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「 FUTURE 」

INCREDIBLE HISTORY

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HOW IT WORKS

bookazine series





HOW IT WORKS BOOK OF INCREDIBLE HISTORY CONTENTS

Ancient History

- 010** Mesopotamia: The creators of civilisation
- 016** How Vesuvius destroyed Pompeii
- 018** The genius of ancient Greece
- 024** The art of mummification
- 025** Britain's tribal territories
- 026** Who were the Celts?
- 030** The Terracotta Army



030
Terracotta Army

Buildings, Places & Landmarks

- 034** 10 wonders of the ancient world
- 040** Inside a Japanese castle
- 041** The Fogong Temple Pagoda
- 042** The Washington Monument
- 043** Windmills
- 044** Edinburgh Castle
- 046** The history of Central Park
- 048** Florence Cathedral
- 050** How was the Sistine Chapel's ceiling painted?
- 052** The Globe Theatre's story
- 054** Brooklyn Bridge
- 056** What went wrong at Chernobyl?

Weapons & War

- 060** History's deadliest warriors
- 066** Spies through history
- 072** The Siege of Tyre
- 074** Brutal battering rams
- 075** Vickers-Maxim gun
- 076** Meet the musketeers
- 078** Inside the Manhattan Project
- 082** Sikorsky MH-60 Blackhawk



076
Meet the musketeers

110
Record-breaking royals



016
The destruction of Pompeii





154 Prehistoric monsters



034 Wonders of the world



098 Accidental inventions

136 Last days of the dinosaurs



Industry & Invention

- 086 Gruesome inventions
- 092 Medieval writing equipment
- 092 The first hearing aids
- 093 The birth of blue jeans
- 094 The Colossus computer
- 096 Rack-and-pinion railways
- 098 Accidental discoveries
- 102 The Antikythera mechanism
- 103 The corvus
- 103 Automatic doors of the ancient world
- 104 Prehistoric painting



Influential Figures

- 110 Record-breaking royals
- 114 Leonardo da Vinci
- 120 Michael Faraday
- 122 Isambard Kingdom Brunel
- 124 Charles Darwin
- 126 The Wright brothers
- 128 Guglielmo Marconi
- 130 Albert Einstein
- 132 Peter Higgs



Prehistoric

- 136 Last days of the dinosaurs
- 144 Fossils
- 146 The Ice Age
- 154 Prehistoric monsters



Leonardo's machines 114



ANCIENT HISTORY

010 **Mesopotamia**

Gain an insight into the first known ancient society

016 **How Vesuvius destroyed Pompeii**

Find out what happened during the cataclysmic eruption

018 **The genius of ancient Greece**

How its inventions, discoveries and culture changed the world

024 **The art of mummification**

How the Ancient Egyptians preserved their ancestors

025 **Britain's tribal territories**

The tribes that characterised Britain before 55 BC

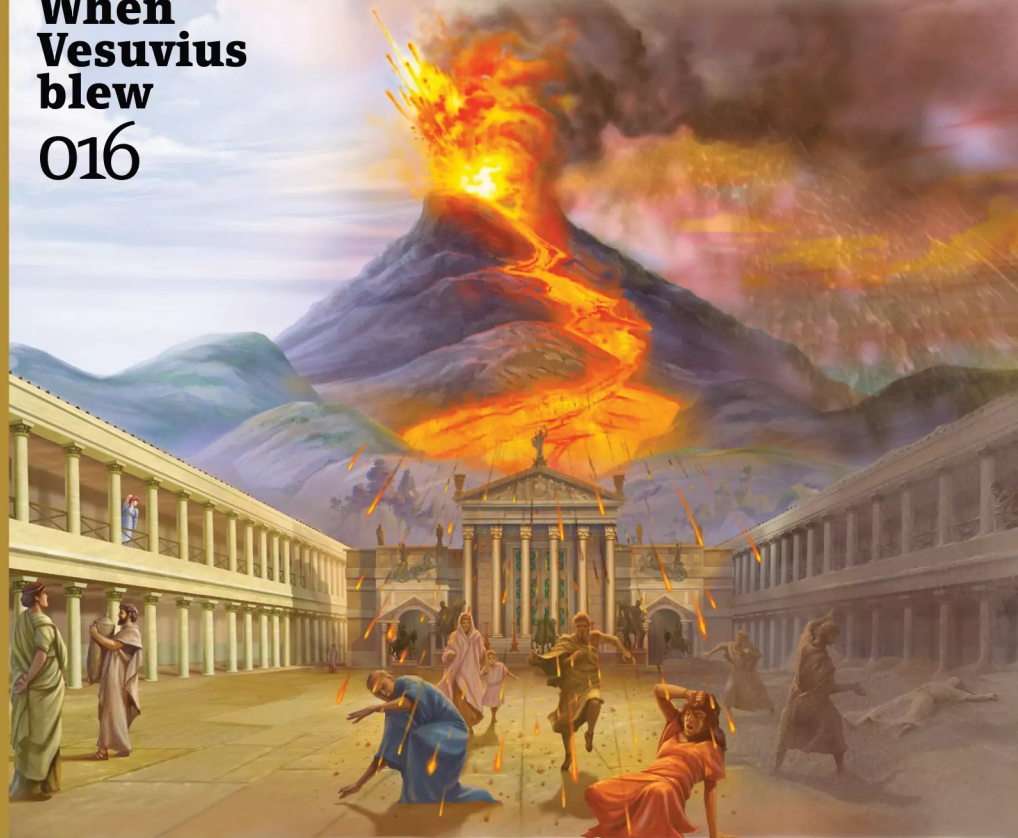
026 **Who were the Celts?**

How the Iron Age revolutionised the Celts

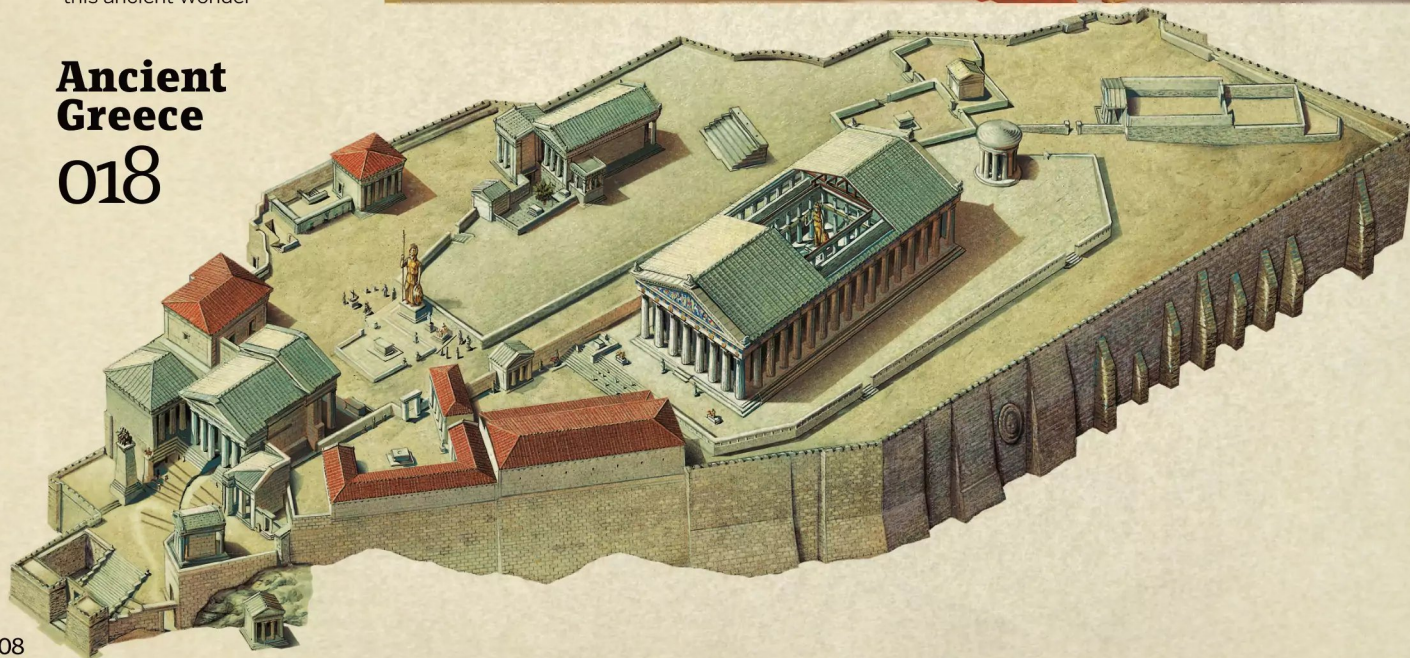
030 **The Terracotta Army**

Get to grips with the scale of this ancient wonder

When Vesuvius blew 016



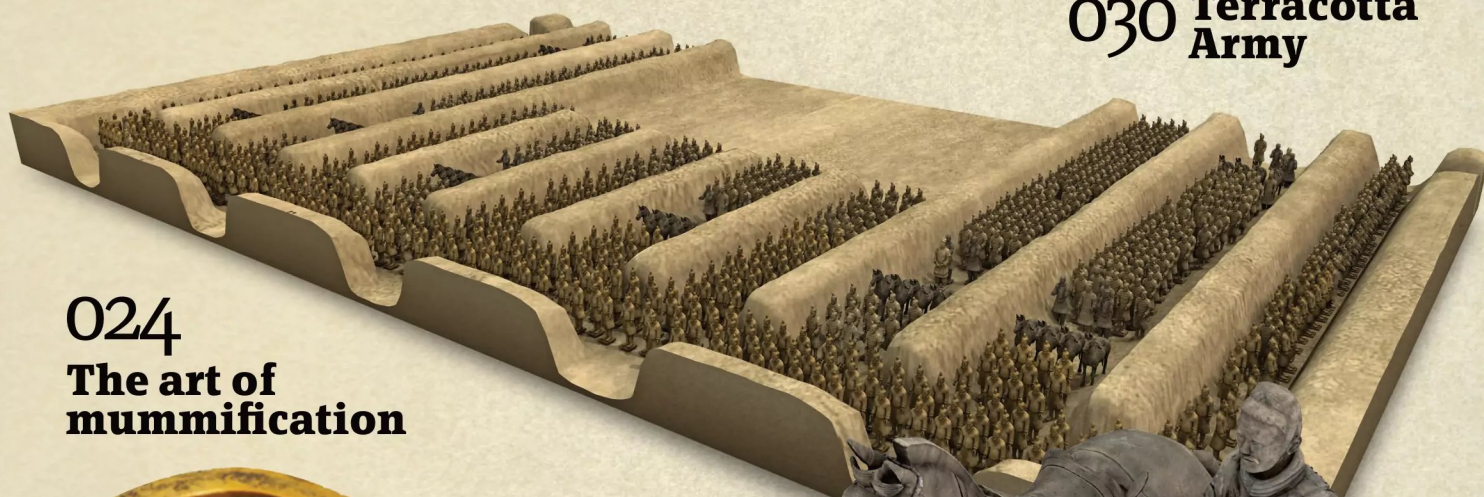
Ancient Greece 018



026
**Who were
the Celts?**



**030 Terracotta
Army**



024
**The art of
mummification**





Mesopotamia: The creators of civilisation

Discover how society as we know it began in a small region of modern day Iraq

The ancient region of Mesopotamia has fascinated, enthralled and perplexed historians and scientists for thousands of years. Unlike the ancient empire of Greece, or even Egypt, it was not a united nation. Made up of a vast collection of varied cultures, city-states and beliefs, Mesopotamia was a land of multiple empires and diverse civilisations. It is perhaps thanks to this variety that Mesopotamia gave birth to what we recognise as civilisation today.

The list of Mesopotamian innovations is endless, and it is difficult to contemplate how modern life would be without them.

Mesopotamia was home to the first ever cities, writing took form there and the oldest wheeled vehicles in the world were found in Mesopotamian ruins. Animals were domesticated, humanity came on leaps and bounds in agriculture, innovative new tools were crafted, weapons were swung and wine was drunk. Mesopotamians were the first people to study the night sky, track the Moon and declare that there were 60 minutes in an hour, and 60 seconds in a minute.

Mesopotamia was driven by religion, and it was one of the few things that united the lands that made up the region. From this religion

sprang customs, moral codes and social hierarchy. In many ways the Mesopotamians were ahead of their time, as women were regarded as individuals in their own right, free to own land, file for divorce and run businesses.

The Mesopotamian version of the Creation story declared that the world was formed when the gods achieved victory over the forces of chaos, and the same could be said in the creation of Mesopotamia itself. With its kings, taxes and trade, it was a triumph of man's ability to conquer and thrive, and it set the blueprints for countless cities, countries and empires that followed.

SUMER

5400 BCE

The city of Eridu is founded; it is considered the first true city in the world.



3600 BCE

Writing first emerges in the form of cuneiform. Reeds are used to make marks in wet clay.



3500 BCE

Religion is first referenced in writing, in the form of Sumerian cuneiform tablets.



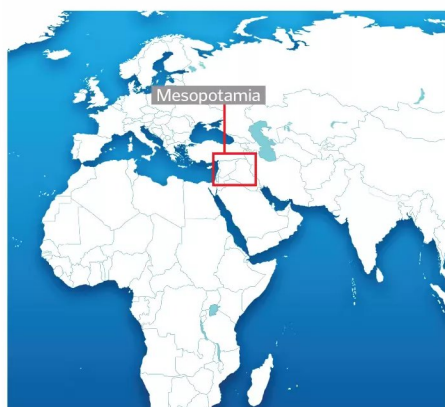
2334-2218 BCE

During this period Sumer is conquered by the powerful emperor Sargon the Great and comes under the rule of the Akkadian Empire.

What it was like to live there

The word 'Mesopotamia' means 'between the rivers', which literally describes the location of the region. Mesopotamia lay between the Tigris and Euphrates rivers, which today flow through modern day Turkey, Iraq and Syria. All the regions of Mesopotamia experienced different geography, which led to variation in how people there lived. Lying between two rivers had some risks as the land was subject to frequent and unpredictable flooding, which could play havoc with farmers' crops. These floods went hand in hand with periods of drought. However, the swelling rivers helped to create very fertile soil that supported plants even with minimal rainfall, and allowed boats to be used as a quick means of transportation. Mesopotamians became skilled farmers and traded their crops for resources they were lacking, such as building materials like wood, metal and stone. The people took advantage of the ready supply of water by building canals to support the trade network and were able to flourish in spite of the lack of natural resources in some areas.

ON THE MAP



The land of plenty

Mesopotamia's unique geography enabled cities and civilisations to rise from the ground

The stone city

For 50 years, Nineveh was the largest city in the world

A perfect union

Along with the Euphrates, the Tigris formed what is known as the 'Fertile Crescent'

The centre of trade

The city of Assur laid on a lucrative trade route

The source of life

The Euphrates is the longest river in western Asia, at about 2,800km long

The first city

Uruk was a place of firsts - writing, architecture and cities themselves

"Mesopotamia, with its kings, taxes and trade, was a triumph of man's ability to conquer"

The rise of civilisation

Three of the major cultures that arose in Mesopotamia and influenced society

SUMERIANS

The southernmost region of Mesopotamia, Sumer comprised modern day southern Iraq and Kuwait. Sumer was first inhabited in approximately 4500 BCE, or possibly even earlier. It is in Sumer that the first cities in the world were established, starting with Uruk. Sumerians believed that their cities represented god's triumph over chaos.

BABYLONIANS

Meaning 'gate of the gods', Babylonia lay in central southern Mesopotamia (modern day Iraq). Its earliest days are a mystery lost to rising sea levels, but from 1792 BCE the famous king Hammurabi came into power and the city of Babylon - built upon the Euphrates river - became the beating heart of Mesopotamia.

ASSYRIANS

Located in the Near East, the ancient kingdom of Assyria comprised regions of Iraq, Syria and Turkey. It drove technological, scientific and warfare developments in Mesopotamia. The Assyrian empire gradually expanded to unite most of the Middle East, increasing their power and wealth to become a formidable force.

2150-1400 BCE

The *Epic of Gilgamesh* is written during this time. This famous poetic work stands as one of the oldest pieces of western literature in existence.



2100 BCE

The Sumerian King List is created, establishing the idea of kingship as a divine institution.

1800 BCE

All the cities of Sumer, and of Mesopotamia, are united by Hammurabi, who makes Babylon his capital.

1750 BCE

A combination of invasion, migration and the sacking of Ur brings an end to the Sumerian civilisation.





The world's first cities

With its reliable source of food, people gathered in Mesopotamia and formed the very first cities

Mesopotamia was home to some of the very first cities in existence, leading many to link it to the birth of true civilisation. The origin of these cities is still unknown today, although many theories exist. One suggestion is that the development and building of temples created a place where people would gather, and thus served as points of contact between different groups of people.

Others believe that people sought sanctuary from natural disasters. As the Mesopotamians were able to develop technology to help them control the nearby rivers, such as levees, they could ensure a good crop. They had no need to be

nomadic, and were able to settle in one place comfortably. It is for this reason that all the early cities were built along the two major rivers.

From the moment the Sumerians began to form these cities, it forever altered human history. People went from being ruled by nature, to attempting to control it and make it work for them. By 4500 BCE the first recorded city rose in the form of Uruk. However, the only urban structure at this point was the temple, which regulated all economic and social matters.

The central purpose of these early cities was to help regulate trade, as southern Mesopotamia

was reliant on outside resources. This need encouraged the spread of urbanisation. However, communication between the cities was difficult, so each city developed into an individual city-state. This led to territorial disputes and, inevitably, war.

In order to keep their cities protected, the Mesopotamians built fortifications, and walled cities rose. Migration to these cities increased, and more buildings were erected. Cities gradually expanded and rulers were proclaimed, who then began looking outwards for trade and conquest.

Processional Way

The Processional Way was a road that ran through the city and connected many of Babylon's central buildings and temples.

A designed city

Mesopotamian cities were among the first to involve urban planning, and there is evidence that cities such as Babylon were built to fixed plans.

Multi-purpose gate

Gates in Mesopotamia were for more than protection; they were sacred places of worship, where public performances were viewed and where kings made appearances.

The gate of kings

The astonishing Ishtar Gate was the eighth gate and main entrance of the city of Babylon. Covered with lapis lazuli-glazed bricks, it was a gleaming, shimmering light in the Babylonian sunshine. It sent a strong message to any enemies: Babylon was a city favoured by the gods. At 12 metres high, the doors and roof were made of cedar, while the gatehouse featured 15-metre-high walls adorned with images of animals and flowers. The gate was constructed by King Nebuchadnezzar II to impress not only his people, but also the gods.

Multi-storey living

Most Mesopotamian cities featured buildings with multiple levels for housing. Even the poor had three levels of living space.

Walls of Babylon

The walls of the city were considered impregnable as they reached up to a massive 27m in height.

1894 BCE

The first Babylonian dynasty emerges; this Amorite dynasty forms a small kingdom including the city of Babylon.

1792 BCE

Hammurabi begins his reign as ruler of Babylon. He transforms it from a tiny town to a powerful city.



1792-1750 BCE

During his reign, Hammurabi introduces some of the earliest examples of laws in the form of the Code of Hammurabi.



1755 BCE

Hammurabi conquers and unites Mesopotamia under his rule, and Babylon becomes known as a holy city.

Towering temples

Ziggurats were temples built on high, stepped platforms. Although they originated in Sumerian cities in 2000 BCE, they gradually spread to all of Mesopotamia, including Babylonia and Assyria. The stepped towers were mainly constructed from sun-dried bricks layered between reeds. It is believed that many ziggurats featured a shrine at the top, but no examples of this remain.

Although their exact purpose cannot be verified, it is known that ziggurats were linked to religion, and each ziggurat was connected to

large temple complexes. There was a belief in Mesopotamia that the gods resided in the Eastern mountains; therefore building high temples would more closely connect the people with god, linking heaven with Earth.

A practical purpose of the high platforms was to escape any rising floodwater that rushed into the lowlands. The structure of the ziggurat, which was accessible only by three stairways, also ensured that the rituals conducted within remained secret and sacred.



The facade and stairway of the ziggurat of Ur have been reconstructed by the Iraqi Department of Antiquities

An unsteady base

Bricks were sun-baked, so the buildings were unstable and had to be routinely destroyed and rebuilt. This caused the level of the cities to gradually rise

Etemenanki tower

At the centre of Babylonian life was the Etemenanki ziggurat. It had seven storeys, measured 91m tall and may have even been finished in silver and gold

Hanging gardens

Possibly built by King Nebuchadnezzar II, if they did indeed exist, the hanging gardens were an astonishing feat of engineering

Irrigation

Because of the unpredictable flooding of the river, Babylonians developed a complex series of ports and canals, as well as dams across the city

Euphrates river

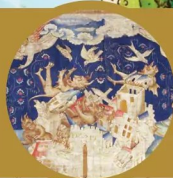
The river ran through the city and was used by merchants and craftsman to transport and trade their goods across Mesopotamia

Circa 1750 BCE

Babylonian mathematicians introduce the concept of place value in numbers. Astronomers also name the planets and constellations.

1595 BCE

Babylon is sacked by the Hittite king Mursili I. This marks the beginning of the Babylonian 'dark ages'.



1595-1155 BCE

The Kassite dynasty rules over Babylonia. They rename Babylon 'Kar-Duniash' but it continues to serve as the capital of the kingdom.

1225 BCE

The Assyrian ruler Tukulti-Ninurta I destroys the armies of Babylon and sacks the city. He goes on to become king.



Seven ways Mesopotamia changed the world

The phrase 'the foundations of civilisation' is often used while talking about Mesopotamia. But what exactly does this mean? Is civilisation simply people living together, or does it involve more? Agriculture had emerged by 8000 BCE, and art was produced for thousands of years before Mesopotamia rose. However, Mesopotamia took these aspects of human culture and transformed them into civilisation as we know it today.

Brought together by a common goal – to find food – the Mesopotamians developed some of the earliest writing known to man, borne out of necessity to record accounts and crop yields. However, it later developed to represent more abstract ideas. As people were gathered together, spiritual practices were also refined, and the population began to share a common belief system. With this established, the priests, who claimed to be able to communicate with the gods, took their place at the top of the social hierarchy, and slowly a class system developed. This emphasis on religion inspired moral codes, which led to formal rules and, in turn, punishment for those who disobeyed.

A steady food supply meant the Mesopotamians could pursue other aspects of life, such as technology and science. They made groundbreaking advancements in the areas of mathematics and medicine. However, this social structure also revealed the darker aspects of humanity, such as war, slavery and expansion, and with so many people gathered together, diseases spread rapidly.

As the civilisation developed, it inevitably had an influence on other cultures. It is believed that Babylonian astronomy influenced Greece, India and even China. The early Mesopotamian codes of laws also had a profound effect on lawmaking in the Near East, and the introduction of taxes and a standing army influenced countries worldwide. In fact, historians are still exploring the huge impact that Mesopotamia had on the ancient world, and the world we live in today.

The creation of writing

Writing began in Mesopotamia towards the end of the 4th millennium BCE as a way to record crucial information about crops and taxes in pictorial form. These early tablets developed into a script, which bears close resemblance to writing today. This system of writing is commonly known as cuneiform and comprised of wedge-shaped marks in clay. Gradually the number of characters used in cuneiform decreased from 1,000 to around 400, which ensured more clarity in the script. By 2500 BCE cuneiform was advanced enough to portray emotions such as fear and hope.

The word cuneiform itself simply means 'wedge-shaped'



The remains of the Code of Hammurabi were discovered in 1901 in excellent condition



Health care

Medicine in Mesopotamia involved a combination of religious rituals and physical treatments. Mesopotamia had specific doctors with their own offices, beds and equipment and generally fell into two categories – the ashipu, who practised religious medicine, and the asu, who used herbal remedies. Generally these two doctors would work together to treat an ailment. The ingredients used in the various treatments ranged from turtle shell and snakeskin to figs and seeds. Mesopotamian doctors recorded their methods of treatment and diagnosis in medical texts like the *Treatise of Medical Diagnosis and Prognosis*.

Thou shalt obey

Law codes as we know them were first seen in Mesopotamia. One of the earliest is the Code of Hammurabi, which features 282 laws dealing with a huge variety of issues in great detail, from marriage to theft. For example, if a man rents a boat to a sailor and it is wrecked, the sailor has to give the man a new boat. Although it is the most well-known, the Code of Hammurabi was pre-dated by other law codes, such as the code of Lipit-Ishtar and those written by the Sumerian king Ur-Nammu, who described the purpose of his laws as protecting the weak from the mighty.

2600 BCE

The city of Ashur, capital of Assyria, is founded, along with other Assyrian cities.

1813-1776 BCE

Shamshi-Adad I rules Assyria. He expands the empire, secures Assyria's borders and builds up a powerful army.

1472 BCE

The kingdom of Mitanni, a powerful northern Mesopotamian state, annexes Assyria and the land loses its independence.

1365-1330 BCE

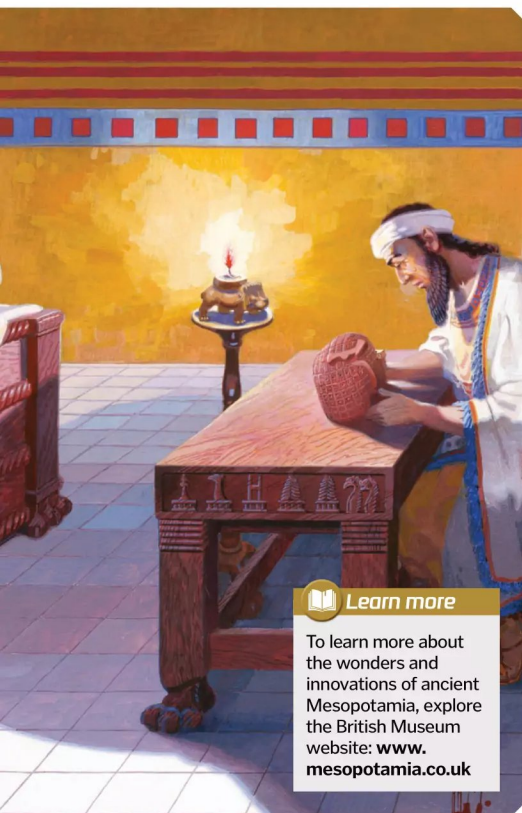
Ashur-uballit I defeats the Mitanni, and under his leadership, Assyria develops as a powerful and rapidly expanding empire.

1244-1208 BCE

The warrior king, Tukulti-Ninurta I, reigns. Assyria expands to its greatest extent and defeats the ruler of Babylonia.

Only the strong shall lead

Mesopotamia was made up of several city-states which each had their own leaders and government, with kings ruling over individual regions. This led to a lot of internal fighting between different kings for land and resources. The first kings were the leaders of armies, who then went on to continue to lead during peacetime. Because of the strong emphasis on religion, the kings often served as high priests and therefore were linked to the divinity of god, and claimed to be god's representatives on Earth. Some of these kings, such as Sargon, sought to unite many of the city-states under one leader and capital.



Learn more

To learn more about the wonders and innovations of ancient Mesopotamia, explore the British Museum website: www.mesopotamia.co.uk



A Sumerian proverb said, "Man is the shadow of god, but the king is god's reflection"

Mesopotamian money

Mesopotamians used silver rings thousands of years before the first coins were made. In around 2500 BCE a 'shekel' of silver became the currency of Mesopotamia, with one month of labour being worth one shekel, and a slave worth between ten and 20. Prior to this, clay tokens in a variety of sizes and shapes were used for trade and barter. There were at least 16 different types of these tokens that represented various things, such as rope, sheep's milk, perfume and honey.



This Carthaginian shekel from 310-290 BCE is similar to the Mesopotamian shekel

The Standard of Ur, an artefact dating from around 2600 BCE, depicts wheeled chariots being used in battle



The basis of time

The Mesopotamians were trailblazers in their concept of time. They were the first in recorded history to use a base 60 numerical system that led to our 60-second minutes and 60-minute hours. Many believe that this helped the Babylonians make such impressive advances in mathematics, as 60 has many divisors. They also used a lunar calendar, which comprised 12 lunar months, at an average of 29.5 days each. This left the Mesopotamians short by around 11 days a year, so they added seven months in each 19-year period to keep the seasons aligned.



The Royal Game of Ur, one of the oldest in the world, was played with early Mesopotamian mathematics

A wheely late invention

The wheel was actually invented at a surprisingly late point of human history, with the oldest example from Mesopotamia dating to 3500 BCE, in the Bronze Age. It is likely that the wheel was developed individually by different cultures around the same time. Evidence shows that Mesopotamians used this invention for pottery first, before adapting the design for transport with chariots. Wheels did offer advantages to transportation, but they took a great deal of time to make as smooth as possible, so sledges were still commonly used alongside the wheel.

1000 BCE

Assyria establishes the first cavalry force. As this is before the invention of saddles, the warriors ride bareback.



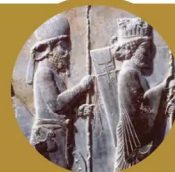
668-627 BCE

During his reign, King Ashurbanipal establishes a huge library, housing a collection of thousands of clay tablets.



612 BCE

Many Assyrian cities, including Ashur and Nineveh, are sacked and destroyed by a combined force of Medes, Persians and Babylonians.





How Vesuvius destroyed Pompeii

The catastrophic eruption that buried an entire city

At noon on 24 August in 79 CE, Mount Vesuvius erupted near the bay of Naples in southern Italy, in what would become one of the most devastating natural disasters of ancient times.

The nearby cities of Pompeii and Herculaneum were completely buried by the ash and pyroclasts that spewed from the

volcano, helping to preserve them in extraordinary detail. We also have detailed information about the eruption itself thanks to Pliny the Younger, who wrote two letters detailing what he saw from his mother's house in Cape Misenum. His famous description of the plume as "shaped like a pine" caused this type of eruption to be named a Plinian eruption.

20 hours of terror

How that fateful day unfolded

1 10am, 24 August, 79 CE

For four days prior to the eruption, small earthquakes are felt throughout the city of Pompeii. As this happens every year without consequence, the inhabitants think nothing of it. Many of them congregate in the public forum, the political, religious and commercial heart of the city

2 1pm, 24 August

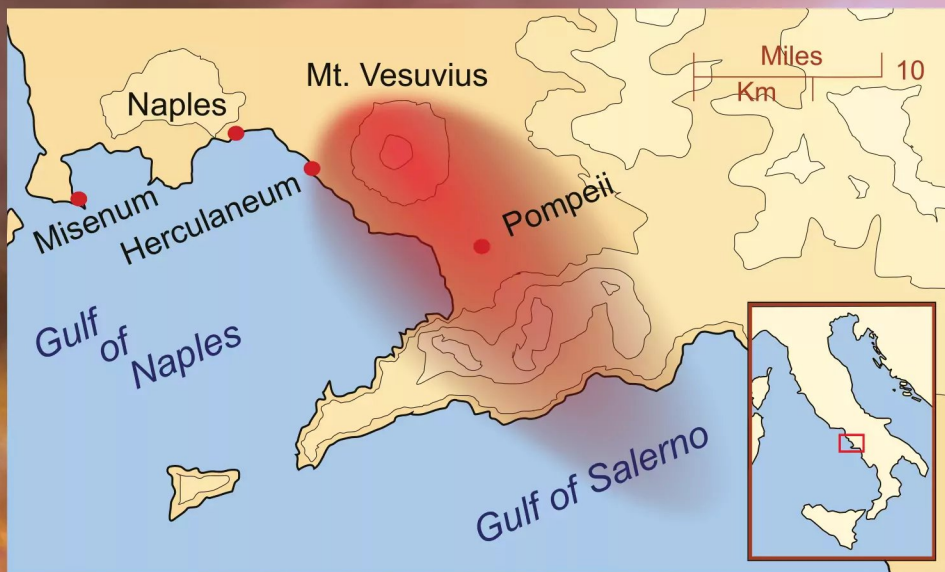
After several small explosions, Vesuvius erupts, sending a tall cloud of lava and ash over 20km into the sky. The cloud blocks out the Sun, plunging everything into darkness, and violent tremors cause buildings to collapse. People run toward the coast in search of rescue, but rough seas make escape by water impossible

3 9pm, 24 August

Hot ash and lumps of volcanic rock rain down over Pompeii, which is downwind from the volcano. People become trapped in their houses as debris blocks the doors, and roofs begin to collapse from the weight of the ash and rock. Many people are also killed by the emissions of sulphuric gases



4 12am, 25 August
The ash cloud reaches its maximum height of 30km and then collapses, sending a pyroclastic surge of hot gas and rock down the volcano's northwest slope toward Herculaneum. Moving up to 700km/h and with temperatures up to 400°C, the surge instantly kills everyone it touches



5 6am, 25 August
As dawn breaks, the cloud collapses for the last time, sending another pyroclastic surge toward Pompeii that kills everyone in its path. By the time the eruption is over, Pompeii is buried underneath five metres of volcanic material, while Herculaneum is buried under 20 metres

"By the time the eruption is over, Pompeii is buried underneath five metres of volcanic material"

Anatomy of the eruption

Initial explosion

After more than 800 years of inactivity, pressure inside the volcano became too great. The built-up gases burst through the thick layer of lava that had plugged the crater and a column of ash climbs upward.



Spreading cloud

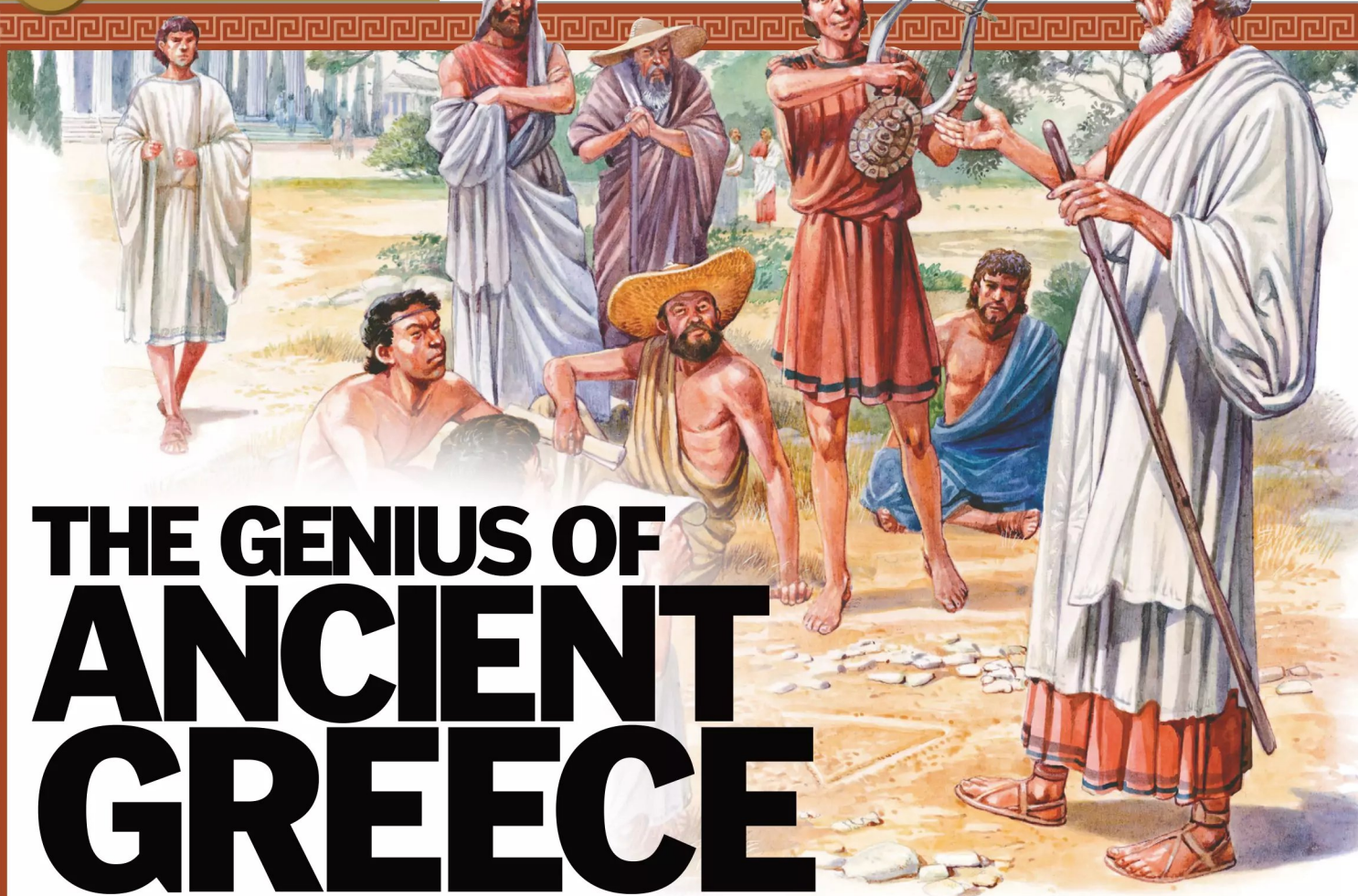
The wind blows the cloud toward the southeast, and it spreads to nearly 100km in width from side to side. Ash falls on Pompeii at a rate of 15cm per hour for an entire day.



Pyroclastic flows

As the ash cloud collapses, volcanic debris rolls down the sides of the volcano toward Herculaneum, which is 6km away, and Pompeii, which is 10km away. Anyone in the path of the flow had their body burned to the bone in seconds.





THE GENIUS OF ANCIENT GREECE

How the inventions, discoveries and culture of this great civilisation changed the world

Ancient Greece was pivotal for the development of Western culture and society. As Europe moved into the Iron Age, Greece was a leading light in the progression of ancient civilisation. Athens is often credited as the key player in this advancement, but other Greek states like Corinth, Thebes, and even the warlike Sparta, also contributed. Ancient Greece improved almost every facet of the economy, society, military and politics. The Greek phalanx was one of the most feared military formations in the ancient world; Greek theatres held the best plays, and athletes competed at the pinnacle of ancient sport: the Olympics.

Greek architects designed some of the finest ancient structures, and philosophers questioned

the world in new ways. Homer's works *The Iliad* and *Odyssey* were unmatched in their time. Unlike civilisations before it, it's believed many educated people in ancient Greece were literate. Hundreds of words in the English language have their origins in the ancient Greek language such as 'encyclopedia', 'telephone' and 'microscope'. The word 'democracy' is another, and it comes from the Greek 'demokratia', which means 'power to the people'.

Greek city-states were ruled by kings for the majority of the civilisation's history, but for a brief period around the 5th century BCE, Athens was a democracy. It wasn't the same system as we know it today (women and slaves weren't allowed to vote), but this incredibly important development

has shaped world politics ever since, and anyone who can vote today owes it to the Greeks.

The divisions of the city-states curtailed scientific advancement as regions often fought among themselves. Finally unified under Alexander the Great in 336 BCE, Greek trade boomed and its culture spread throughout the Mediterranean, Asia Minor and North Africa. The Romans may have conquered Greece, but they were so impressed by its culture and technology, they copied Greek mythology, engineering, architecture and military tactics. The influence of ancient Greece is so important to the Western world that if it had been destroyed during its many conflicts with Persia, European civilisation could have turned out very differently.

Major events in ancient Greek culture

6000 BCE

First human settlement

The first Neolithic activity in Greece, including evidence of early agriculture.

2700 BCE

Minoan civilisation on Crete

The Minoan civilisation blooms under a system with no hierarchical structure.

1500 BCE

Mycenaean era

Greece is now in the Bronze Age and the Mycenaean culture develops the Greek language.



c.900 BCE

First pottery

Made in a classical geometric style, the first pottery unique to Greek culture is made.



Greek city-states

The most powerful and influential territories in Greece's classical era

Olympia

The location of the first Olympic Games was a sacred site in ancient Greece. Olympia also held the Heraia Games for women, and had many temples dedicated to the worship of the gods



Delphi

Delphi had some of the most important temples in all of Greece. It is said to have been home to the oracle Pythia, and Greeks would travel to seek her wisdom

DELPHI

Corinth

Known for its high quality pottery, Corinth was a major trading and educational centre in ancient Greece. The city-state had its own currency and was home to a major type of classical Greek architecture



Thebes

The most powerful city-state before the rise of Athens and Sparta. Thebes enjoyed a heightened period of power after siding with Sparta against Athens. In Greek mythology it was the birthplace of Hercules

THEBES

CORINTH

ATHENS

OLYMPIA

SPARTA

Sparta

The warlike city-state had a powerful army and helped protect Greece against the Persians. Every male citizen was a warrior, taught from age seven, to form a professional and widely-feared army



Athens

One of the most powerful and wealthy city-states, Athens had a strong navy and the first democracy. It had a long-standing rivalry with Sparta that eventually resulted in war



Macedonian unification of Greece

The Peloponnesian Wars (431-404 BCE) tore Greece apart, with the hegemony of Athens broken by Sparta and its allies. Greece remained divided, with a series of uneasy alliances leaving it weak and open for invasion. Around this time the power of Macedonia was growing and King Philip II of Macedon took advantage of a weakened Greece. His army defeated a strong alliance of Athenian and Theban soldiers at the decisive Battle of Chaeronea in 338 BCE. Sparta did not join in the battle but would also later be defeated. Philip was now the undisputed ruler of Greece, and although he was later assassinated, this brought his son Alexander III to the throne. A born leader, Alexander the Great unified Greece under his rule and made it his intention to bring the Persian Achaemenid Empire to its knees. Alexander went on to lead one of the most powerful empires in the ancient world, which stretched from Greece in the west to India in the east.



Philip and Alexander's rule united Greece and established it as a major military power



ARCHAIC PERIOD

c.800 BCE

Works of Homer

The 'blind bard' writes the poems *The Iliad* and *Odyssey*.



776 BCE

Olympic Games held

The first Olympics take place as a festival dedicated to Zeus. The event is held every four years for centuries.



740 BCE

Greek alphabet

Created from a Phoenician script, evidence of the first Greek alphabet is found.

700 BCE

Birth of musical study

Sparta and Argos hold the first organised studies of musical theory and the first documented musical competitions.



The Acropolis

Athens' defining citadel became an enduring symbol of ancient Greek architecture

Many major Greek cities were dominated by an Acropolis at their centre. Meaning 'high city', it was a well-defended hill that citizens would retreat to when the city was under attack. The city-states of Thebes and Corinth both had an Acropolis, but by far the most famous of these citadels stood in the centre of Athens. The original structures were improved after victory at the Battle of Marathon in 490 BCE, but were destroyed by Xerxes' Persian troops when they sacked Athens ten years later.

After the Persian defeat at Salamis, the city used its wealth to restore splendour to the Acropolis. Vast building projects got underway and the area became a huge centre of worship for the goddess Athena, the patron deity of Athens.

The grandest temple of all was the Parthenon, which was constructed between 447 and 432 BCE. It housed a magnificent ivory statue of Athena and was the store of the city's gold

reserves. The area became a place of worship and culture rather than just defence, with the temples of Athena Nike, Erechtheion and Propylaia also built in a 50-year period. With the help of modern restoration efforts, the Parthenon stands above the city to this day.

The Acropolis of Athens

How grand building programmes in the 5th century BCE turned the Acropolis into a sprawling citadel

Athena Nike

Inside the temple was a wooden statue of Athena. She held a helmet and a pomegranate tree to symbolise war and peace

Monumental gateway

Known as a Propylaia, this was a decorative entrance to the complex. Its columns and roofs made it an imposing structure

Acropolis entranceway

The main entrance to the Acropolis was a wide stone staircase that led to the monumental gateway



Natural entrance

The Propylaia was constructed around the natural entrance to the Acropolis and citizens ascended via a ramp and marble steps

Erechtheion

This most sacred temple in Athens was in Greek mythology – the site where Athena and Poseidon disagreed on who would have control of the city



The Acropolis rises 150 metres above Athens and is around six hectares in size



"The area became a huge centre of worship for the goddess Athena"



625 BCE

Advancements in pottery

Black figure pottery becomes popular in Greece, but is later superseded by red figure pottery.



621 BCE

Draco's code of law

Devised by an Athenian aristocrat, these became the city's first written law codes and legal system.

594 BCE

First coins

Athens now uses a currency as trade and industry begin to develop.



508 BCE

Birth of democracy

'The father of Athenian Democracy', Cleisthenes introduces a new political system as the public become involved in politics.

CLASSICAL PERIOD

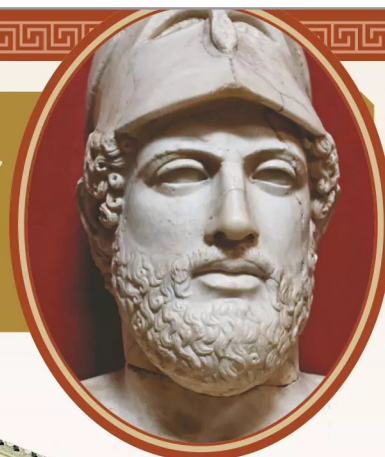
The Parthenon

The popular Athenian general and statesman Pericles was the driving force behind the reconstruction of the Acropolis after it was destroyed by the Persians.

Pericles wanted the citadel to be larger and grander than ever before. The project was an expensive venture and Pericles skillfully used tributes paid to the city to fund it. Many of the finest architects and sculptors of the ancient world, along with hundreds of labourers, contributed.

Pericles is remembered as a hero of Athens and shortly after his death from the plague, the city lost the Peloponnesian Wars against Sparta and entered a period of cultural darkness.

Under Pericles' leadership the city entered a golden age of prosperity



Sanctuary of Zeus Polieus

An open-air sanctuary with a small barn nearby, oxen were sacrificed to Zeus here once a year in the annual ritual of Bouphonia

Theatre capacity

17,000 spectators could cram into the theatre's tiers of stone seats to enjoy some of the most famous ancient Greek plays



Parthenon

The grand centrepiece of the Acropolis was built without concrete and was held together with iron clamps

Theatre of Dionysus

Dedicated to the patron god of drama and wine, it was one of the oldest Greek theatres

The Panatheniac Games

The most important of all the Athenian festivals was the Panathenaea. A rival to the Olympic Games, it was celebrated every four years and held all over the city for around a week between July and August. The Games were based around three types of contests: musical, gymnastic and equestrian, and included hoplite races in full armour and pankration (a brutal mix of wrestling and boxing). The event was organised by ten administrators called the Athlothetai, and men, women and children all competed in the events, from professional athletes to freed slaves. The winners were mostly presented with valuable prize amphoras, which they often sold for coin. Champions gained so much money that they could make a career out of participating in these festivals.



The Games held a pentathlon including running, javelin, discus and long jump

483 BCE

Mining precious metals
Athens establishes silver mines, which allow Themistocles to create a fleet to defeat the Persians at Salamis.

468 BCE

Development of the theatre
Tragedian Sophocles writes plays for theatre, which become immensely popular.

447 BCE

Building the Parthenon
Construction begins on the Parthenon, a temple dedicated to Athena, the goddess of wisdom and war.

420 BCE

Atomic theory of matter
Philosopher Democritus hypothesises the existence of atoms and different types of matter.



Innovations and inventions

The ancient Greeks devised many clever mechanisms and systems that are still used today

From the Olympics to democracy, Greek civilisation had a huge impact on the West. The Babylonians may have created the first maps, but it was the Greeks who pioneered the study of cartography. Philosopher Anaximander drew up the first world map, which was divided into two sections: Europe and Asia. The Greeks also revolutionised the field of geometry with Pythagoras' theorem and the refined value of pi.

Before the Greeks, ancient civilisations blamed disease on the wrath of gods. While the Greeks still believed in divine retribution, physicians like Hippocrates observed patients suffering with conditions and recorded signs and symptoms. This helped to advance surgery, anatomy and public health. There was also progress in the knowledge of the natural world, with the differences in plants documented for the first time. Greek thinking also resulted in inventions like the buckle, metal anchors and the crane.

City-states like Athens were built to a set plan. Surveyors devised streets and squares with enough room for theatres, markets and temples. This is one of the first recorded instances of

urban planning, and provided cities with space and facilities. Multiple urban areas were based around the Hippodamian Plan: a city in a rectangular grid – helpful for navigating and organising the streets for both economic and defensive reasons.

Perhaps the most obvious relic of ancient Greece today is its architecture. Ionic and Doric columns are still used on many neoclassical buildings around the world, such as the US Capitol building and the Arc de Triomphe.

Even after the fall of ancient Greece, its legacy lived on. The Roman Empire was inspired by Greek mythology and built upon many Greek ideas of geometry, astronomy and culture.

The Archimedes' screw

The physics of Archimedes' screw, an ingenious Greek invention for raising up water or grain

Turning the chamber

A hand crank turns the spiral chamber, which scoops up the water or grain to carry it upwards

Specialised shape

A helix turns inside a hollow wooden cylinder and the rotation creates upward momentum

Incline

The screw's plane is angled at about 45 degrees and is much easier than using buckets

Uses

Archimedes designed the screw to help with irrigation and to remove water from Greek ships

Modern uses

Today, the system is used in water treatment plants to pump sewage, and to reclaim land below sea level

No spillage

The shape of the continuous screw holds the water, not allowing it to trickle back down

Other Greek inventions

Inventions we still use today, from the shower to the alarm clock



Alarm clock

They worked by using a dial to indicate the time, which would sound with the drop of pebbles onto drums.



Water mill

The water mill ground grain to produce rice, flour, lentils and cereals, important for feeding the population.



Odometer

This mechanical instrument measured distance and was used by the Romans to help build their roads.



Shower

The Greeks were the first to use piped water to shower themselves. The showers were fed by a plumbing system.

380 BCE

The Athens Academy
Plato opens the first Western higher learning centre to educate students on mathematics and science.

c.359 BCE

Invention of the catapult
An early stone-throwing siege machine is invented in 4th century BCE, and becomes a commonplace weapon in large scale conflict.

336 BCE

Alexander the Great
The Macedonian king Alexander spreads Greek language and culture through Asia via an expansive and formidable empire.



335 BCE

Aristotle's lyceum
Alexander's tutor founds a school to rival Plato's that lectures students on physics and biology.

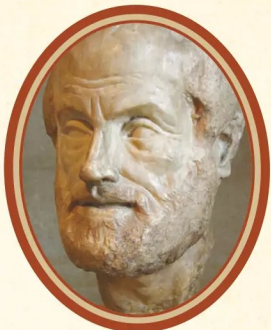
HELLENISTIC PERIOD

Great Greek minds

Meet some of the most prominent thinkers in all of ancient Greece

HIPPOCRATES

Hippocrates was one of the first to observe the effect diseases had on the body. He separated medicine from religion, and by recording what he saw – whether it was a pale face or dry skin – he helped develop methods to prevent and cure diseases.

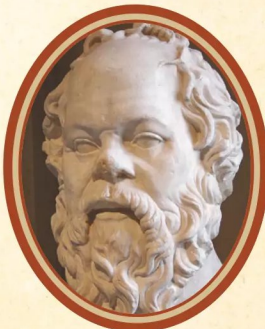


SOCRATES

Socrates was a renowned philosopher, and Socratic teaching concentrated on asking questions, fostering debate and forming ideas through conversation. The Socratic method is still used by educators today to encourage their students to think critically.

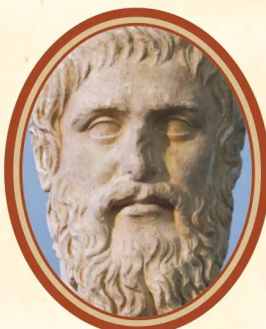
ARISTOTLE

The so-called father of logic wrote over 150 works and spoke on the topics of philosophy and biology like no other. He believed that existence was based on achieving personal happiness.



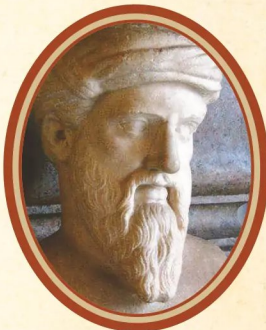
EUCLID

A leading mathematician, Euclid wrote 13 books known as *The Elements*, which collected 300 years worth of ancient ideas on geometry. Euclid made these earlier works accessible to many and it has become incredibly influential in teaching.



PYTHAGORAS

Known as the father of numbers, Pythagoras is world-renowned for his eponymous theorem for deducing the length of the third side of a triangle. Many works were published in his name by his loyal followers.



PLATO

The teacher of Aristotle was a student of Socrates who spread his mentor's teachings. He lends his name to the idea of Platonic love and founded the first higher learning institute in the West.



What the Greeks did for us

The legacy of ancient Greece in the 21st century



Olympics

Dedicated to Zeus, the Olympic Games first took place in 776 BCE.



Hippocratic oath

This sacred oath was written by Hippocrates and promises that a doctor will do everything they can to help their patient.



PEER JURY

The justice system and the concept of a trial were advanced in Athens.

Philosophy



The Greeks were the first to constantly question the world and develop new scientific methods of thought.

Theatre

Both dramas and comedies were performed in front of audiences.



SPHERICAL EARTH THEORY



Pythagoras was the first person to propose that the Earth was a sphere after observing our round Moon.

Democracy

For a time, male Athenian citizens had equal political rights and freedom of speech.



A α
B β

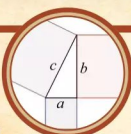
Language

The ancient Greek writing system inspired the Latin alphabet and is still in use.

"City-states like Athens were built to a set plan"

c.300 BCE

Mathematical advancements
Mathematician Euclid writes *The Elements*, an influential collection of 13 textbooks on geometry, which included work on Pythagorean theorem.



c.250 BCE

Archimedes' screw
The great Greek polymath Archimedes conceives the Archimedes' screw, just one of his many inventions.



238 BCE

Syracuse theatre
A popular Greek theatre is expanded significantly into one of the largest known in the ancient world.

146 BCE

Roman Greece
The Romans invade Greece. Impressed by Greek architecture, cities become tourist attractions and many customs are copied.



The art of mummification

Mummies have been found in many parts of the world, but Egyptian mummies are the most well-known due to their distinctive appearance and unique embalming process

Ancient Egyptians used to bury their dead directly in the hot sand, which dried and preserved them somewhat. When they began using caskets, the bodies decayed instead. Around 2600 BCE, Egyptians began experimenting with a way to preserve their ancestors. They learned that bodies decayed from the inside out, starting with their organs. Embalmers perfected a process by which the organs were removed and the body dried prior to burial. This practice, known as mummification, was used for nearly 3,000 years.

Mummification was an expensive process and could take up to 70 days to complete. The embalmers worked in open tents, out in the desert and away from the general population. After washing the body, they removed the brain from the skull. In order to get into the brain cavity, embalmers put a chisel up the body's nose and hit it with a hammer to crack through the bone. Then, they inserted a long hook to pull out brain matter.

After cutting a slit in the left side of the body, embalmers removed the abdominal organs. They were washed, wrapped in linen and packed in jars. Natron, a naturally occurring salt, was added as a drying agent. The body was rinsed with wine and filled with incense and natron, then covered with more natron. A slanted table allowed fluids to drip from the body as it dried while guards kept away scavengers. Once the body was dry, embalmers wrapped it in linen strips in several stages and coated it with resin. The linen helped keep the body together and prevented moisture from entering. A rigid scaffold was then fitted over the body and a funeral mask attached to the face. Finally, the completed mummy was placed into a container decorated to look like a person, called a *suhet*. ✨



An extreme way of wrapping up warm for winter

"The practice of mummification was used for nearly 3,000 years"



Britain's tribal territories

Before the Roman invasion in 55 BCE, Britain was characterised by a large number of ancient tribes, each with its own culture

While the first modern humans populated the area we now call Britain at the end of the Ice Age (6,500 BC), very little is known about the intricacies of their culture and peoples until recorded history begins circa the Roman invasion of 55 BC. Indeed, if it were not for the Roman chroniclers of the time such as Tacitus and Ptolemy, who met the ancient tribes of Britain either in trade or in war, our sketchy picture of these peoples would be even more incomplete than it is today. However, centuries of historical records, stories and archaeological finds have at least given us a snapshot of their lives, leaders and customs.

Before the Roman invasion there were over 27 separate tribes living in Britain. These people had grown from the early hunter-gathers who had inhabited the area, and later the farmers who had developed agriculturally focused societies and who had built such sophisticated structures as Stonehenge. For the last 600 years BCE though, influenced much by the arrival of the Celts from the continent, expansionist tribal kingdoms headed by dynastic and highly territorial rulers and chieftains arose, delivering cultures of fierce violence and sophisticated manufacture, artistry and trade.

While the Romans are often credited with bringing a unified currency, as well as structured towns and a host of amenities and technology, these features – at least in part – were already integrated into areas of British tribal society. Some tribes such as the Venicones buried their dead in stone casings, very much akin to a tomb or coffin. Others, like the Iceni, Catuvellauni and Atrebates, had already created and distributed currency throughout their territories.

Over 200 years, however, from 55 BCE until well into the 2nd Century AD, the ancient tribes of Britain were either conquered or indoctrinated into the Roman empire, a process that largely converted the population's attitudes and cultures to those shared on the continent and saw a gradual climb in society towards standards of administration, architecture, sanitary systems and health care that resonate with today's society. 🌿



Head to Head ANCIENT BRITISH TRIBES

MOST REBELLIOUS



1. Iceni

Located: Norfolk

Facts: One of the most rich and powerful tribes in Britain, the Iceni revolted against the Romans after the death of their client-king Prasutagus and were led until her death by Prasutagus' wife, the renowned Queen Boudicca.

MOST CIVILISED



2. Catuvellauni

Located: South-east

Facts: One of the most pro-Roman tribes, the Catuvellauni quickly adopted Roman lifestyles and, as a result, were made very rich and powerful. One of the most famous British tribal kings, Cunobelinus, originally heralded from the Catuvellauni.

MOST DEFENSIVE



3. Durotriges

Located: Dorset

Facts: A southern tribe, the Durotriges differed from others by remaining largely in hill forts long after others had abandoned them. They were huge traders and, through numerous harbours, exchanged many goods with the Romans.

Maiden Castle, a great example of an Iron Age, multi-ditch hill fort





The ancient Celts

How the Iron Age revolutionised this pre-Roman civilisation

The discovery of how to extract iron from its ore changed the world. As the Iron Age was born, new tools could be made for warfare, agriculture, hunting and fishing. Among the main beneficiaries of this new age were the Celts. The Iron Age in Europe lasted from 800 BCE until 43 CE and signalled a significant development of society.

Ploughs, scythes and sickles were fashioned to tend to and gather crops. Rotary querns were introduced to turn grain into flour and hunting tools became sharper and tougher. With iron, an array of swords, helmets and armour could also be fashioned. Clothing accessories developed too, with the creation of iron brooches and torcs.

The Celts lived in small farming communities, often in hill forts for protection. The houses had thatched roofs and one of the biggest settlements in Britain was Colchester, believed to be the oldest town in Britain.

If there was any negative aspect to living in the Iron Age it would definitely be their medicine. Still very primitive and led primarily by druids, one of the only surgical operations was the trepanning procedure. Headaches were believed to come from evil spirits so if you were feeling under the weather, a hole was drilled into your skull to release the demons. With the coming of the Iron Age and sharper, tougher tools, archeological evidence has shown that this gruesome practice was still popular.

It seems the Celts had an obsession with the human head. They believed the head harboured the soul and that's why, after a victorious battle, they would cut off the heads of fallen enemies and display them on their houses, both as bragging rights and as a scare technique to warn anyone who messed with them.

A Celtic hill fort

Discover how Celtic farming communities worked

Well

Without the technology of aqueducts, water was collected from rain or nearby springs for the hill-fort community

Outdoor fire

Outdoor ovens were used to cook bread and meat to feed the whole fort



Construction

A roundhouse was typically constructed from a wooden frame with a straw roof

A reconstructed roundhouse like the ones Celts lived in

Celtic cities

Celts lived in small communities led by a chieftain and a band of warriors. There were few alliances among the different tribes and no sort of centralised state or government

Distribution

The buildings within the fort's society served different functions and roles to ensure survival and development

Indoor fire

The indoor fire was sometimes used for extra cooking but primarily for warmth in the harsh winter months

Who were the Celts?

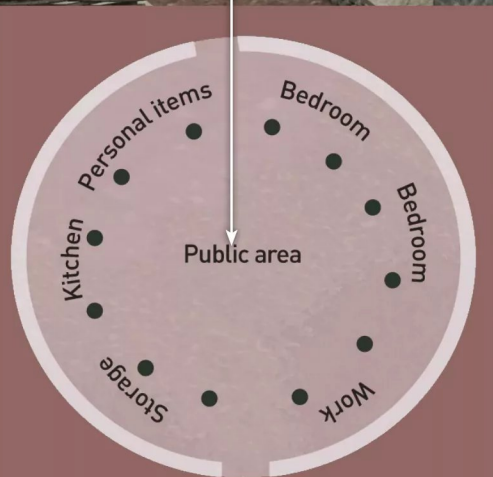
A term used for many different tribes, the Celts varied from region to region. For instance, the Gauls were based in what is now France and the Celtiberians were located in modern day Spain and Portugal. As their European influence began to come under threat from the Romans and Saxons, many migrated to Britain around 500 BCE. Despite invasions from the Romans, Angles, Saxons, Jutes and Vikings, the Celts still remained established inhabitants in many areas of Britain by the 8th century. However, their lands were now pushed back to Wales and Scotland rather than England, which was primarily Anglo-Saxon territory. Their influence can still be seen today with the uncovering of the Tal-y-Llyn hoard of Iron Age metal tools and weapons and substantial evidence of Celtic hill forts in Maiden Castle and Old Oswestry.

The remains of the Celtic hill fort at Maiden Castle



Hill fort location

Often surrounded by a wooden or stone wall, both natural and man-made defences made the fort tricky for enemies to breach





How the Celts fought back

The Celts had a reputation for being fearsome warriors, but the advent of the Iron Age made Celtic Britain even more resistant to overseas attack than before. The mighty Roman army took three attempts to conquer Britain and continually struggled to rule over large parts of the island, especially in Scotland and Wales. The Celts had access to the technology to make their own swords, spears and axes, as well as shields for protection. According to both Greek and Roman historians, the Celts would often go into battle without armour or even completely naked, covered only in war paint.

Although there is some evidence to suggest that they used helmets and body armour, these were apparently rare, possibly only used by chieftains and high-ranking warriors.

The Celtic military was primarily based around infantry, but they also used chariots and – occasionally – cavalry during battles. Their tactics weren't as advanced as the Roman testudo, for instance, but they still had some bold strategies up their sleeve.

The most famous is perhaps the *Furor Celtica*. Translated to 'Celtic Fury', it was a mass charge on the front of an enemy line that was used to disrupt and split enemy ranks. Celts on the continent were known to be more defensive and used a tight phalanx set-up, much like the original Greek formation.

The Celtic tribes had many iconic chieftains such as Vercingetorix, Caratacus and Cassivellaunus, but the most famous, without a doubt, was Boudicca (or Boadicea). The fierce and influential warrior queen

of the Iceni tribe, she led a resistance force against the Roman invaders. Successfully forming an alliance with various other clans around the British Isles, her forces defeated the Roman ninth legion and sacked the Roman-ruled Colchester, Londinium (London) and Verulamium (St Albans). Boudicca was finally defeated by Roman general Paulinus at the Battle of Watling Street, but the Iceni's stand proved that Roman rule was far from invincible.



What tools and weapons did the Celts use?



Sickles & scythes

Used to cut crops and chop wood, iron scythes and sickles made farming and building simpler and quicker.



Ploughs

The 'ard' broke up fertile soil for crops so large communities could be fed, a big reason for the Iron Age population increase.



Spears

The advent of iron smelting brought tougher and sharper spears. These helped in hunting large game and were also used in warfare.



Helmets

The Celts donned two types of helmet: the Montefortino and the Coolus. The latter was the legionnaires' helmet of choice.

There were other types of settlements

Hill forts were the most common type of settlement in Celtic Britain, but there were other types of communities too. In Scotland, for instance, brochs were very common. Stone was more readily available than wood in the north so hollow dry stone towers were built. A structure known as a crannog was also popular on the side of the lochs of Scotland.

Hill forts themselves also differed across the British Isles. Where the terrain was not hilly, a plateau or valley fort had to rely on man-made defences for protection. Others were built on river confluences for water access while others were purposely constructed on coastlines. Last of all, some forts were not built with defence as a priority so had smaller walls and enclosures.

Even the buildings themselves differed, with Britain having roundhouses while in mainland Europe, rectangular or square buildings were preferred.



The Dun Carloway broch on the Isle of Lewis, Scotland. It is one of the best preserved in the world

On the map

■ The largest extent of Celtic lands at around 275 BCE

British Isles

Scotland, Wales, Ireland, Cornwall, the Isle of Man and Brittany in France are known as the 'Celtic Nations' where old Celtic traditions and cultures can still be seen and heard

Gaul and Iberia

Historians disagree over the likelihood of a Celtic presence on the Iberian Peninsula where 'Lusitanian Celts' are thought to have settled

The Alps

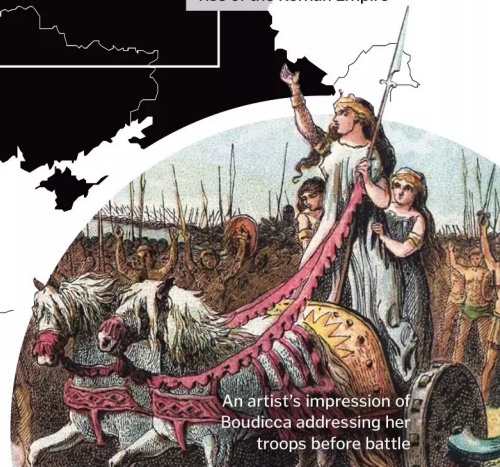
The two main Celtic cultures are believed to be from this area, the Hallstatt and the La Tène

Place of origin

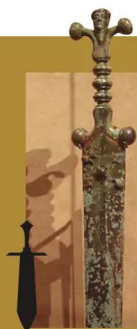
The Celts originated in an area known as 'Hallstatt' in the foothills of the Alps in modern-day Austria

East expansion

The extent of Celtic expansion reached as far east as parts of Romania by 275 BCE before the rise of the Roman Empire



An artist's impression of Boudicca addressing her troops before battle



Longer swords

As iron and steel production techniques gradually improved, longer, double-edged and better balanced swords became a popular weapon of choice in Celtic warfare.



Falcata sword

A typical Celtic sword used in the Iberian Peninsula. A short sword used for quick slashes, it delivered a powerful blow and could split enemy shields and helmets.



Armour

Known as Ceannlann, it was a mixture of linen and metal scales sewn onto chain mail armour. Nobles and rich Celts could afford this, while poor warriors wore leather armour or none at all.



Ranged weapons

The Celtic infantry focused on close-quarters combat, but after witnessing Viking bows, they began to occasionally use slings, bows and spears for attacks from a distance.



The Terracotta Army

Learn about China's ancient warriors for the afterlife

The eighth wonder of the ancient world was discovered by accident. In 1974 in Xi'an, China, a group of farmers were digging when they uncovered a pit containing thousands of life-size warrior statues. The Terracotta Army is part of an enormous mausoleum, built to accompany the First Emperor into the afterlife.

Over 2,000 years ago, Emperor Qin (pronounced Chin) Shi Huang had united the seven warring states into the single nation of China, which gets its name from his kingdom.

The resulting peace meant there was no use for his vast army, so he set them to work building his elaborate tomb.

Much like the whole of Chinese society at the time, the Emperor was obsessed with life after death. He believed that the next world mirrored this one, so commissioned an army of life-size clay warriors to help maintain his rule. The pits were excavated and clay bases were made for each figure. All the body parts were made separately and baked

in a kiln before being joined, in an impressive early example of assembly-line construction. Once complete, each warrior was baked again at 1,000 degrees Celsius to harden the final structure. These advanced methods make that the Terracotta army is a lasting reflection of the ingenuity of early Chinese society.

The Painted Warriors

Thousands of clay soldiers guarded the First Emperor's tomb from the 3rd century BCE

Building an army

1 Gathering clay

Once the pit was dug, clay was sourced locally and pounded into bases, to which the soldiers would be attached



2 Making the parts

Each soldier's arms, torso, legs, hands and head were made using a variety of moulds



3 Assembly and sculpture

Sections were baked and combined to form the clay soldier. Individual facial features were then added



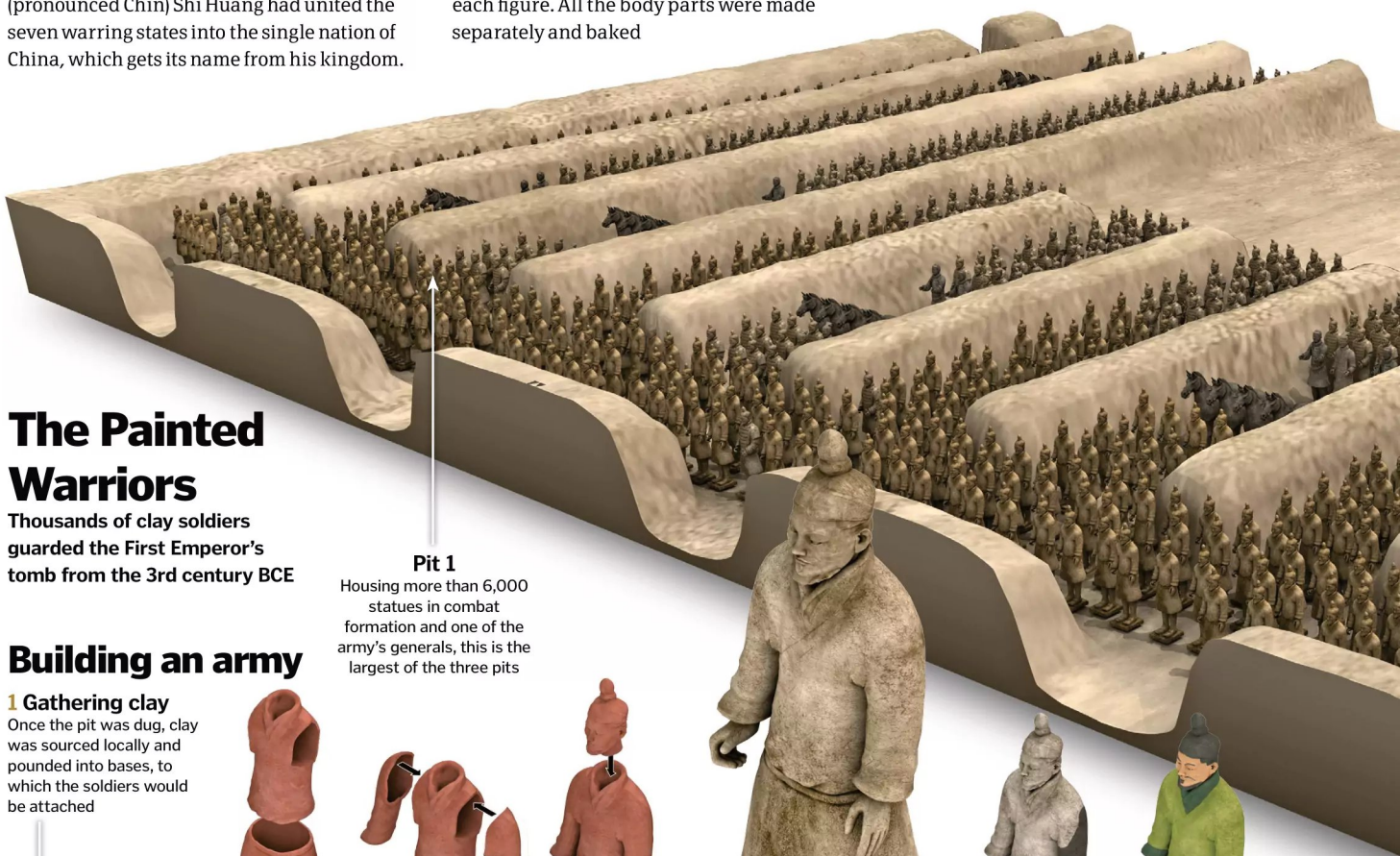
4 Firing the clay

After assembly, the soldier was baked again to harden the clay



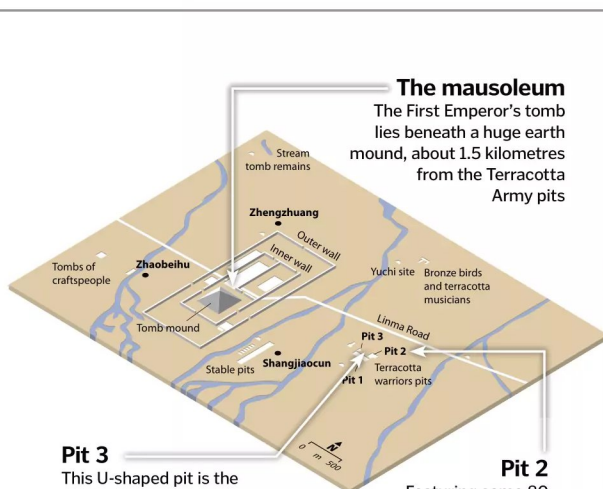
5 Painting

The finished soldiers were painted with bright colours. They were expensive to make and thus symbols of luxury



Pit 1

Housing more than 6,000 statues in combat formation and one of the army's generals, this is the largest of the three pits



The mausoleum

The First Emperor's tomb lies beneath a huge earth mound, about 1.5 kilometres from the Terracotta Army pits

Pit 3

This U-shaped pit is the smallest, housing fewer than 100 soldiers, four horses and a chariot

Pit 2

Featuring some 80 chariots and an array of weaponry, this pit also contains some 160 kneeling archers

General

Only a few generals have been found, strategically positioned throughout the pit as they would be on the battlefield

Infantrymen

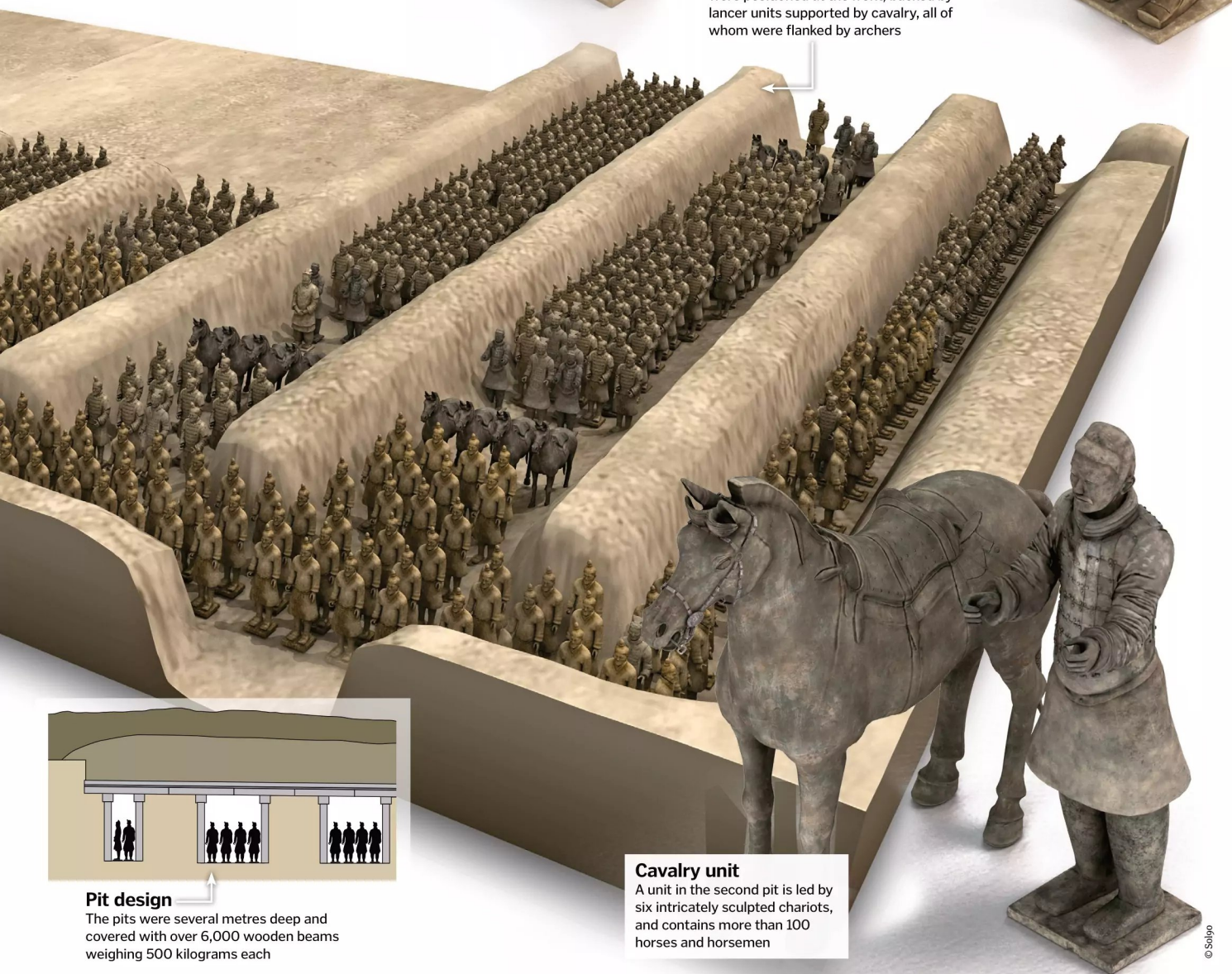
Although made of clay, the infantrymen sport real bronze weaponry, including halberds, spears, bows and crossbows

Combat positions

The army was set out in the standard military formation of the time. The infantry were positioned at the front, backed by lancer units supported by cavalry, all of whom were flanked by archers

Officer

These officer statues were more detailed than those representing the infantry, featuring complex armour



Pit design

The pits were several metres deep and covered with over 6,000 wooden beams weighing 500 kilograms each

Cavalry unit

A unit in the second pit is led by six intricately sculpted chariots, and contains more than 100 horses and horsemen



BUILDINGS, PLACES & LANDMARKS

034 10 wonders of the ancient world
Discover how history's most impressive man-made landmarks were built

040 Inside a Japanese castle
See inside the impressive architectural masterpiece that is Himeji Castle in Japan

041 The Fogong Pagoda
Read about the oldest wooden pagoda in China

042 The Washington Monument
Inside the US capital's iconic marble monolith

043 Windmills
Find out how these towers harness wind power

044 Edinburgh Castle's story
Discover the history of one of Scotland's most iconic castles

046 The history of Central Park
How did such a huge area of New York City go green?

048 Florence Cathedral
Tour this incredible Renaissance masterpiece

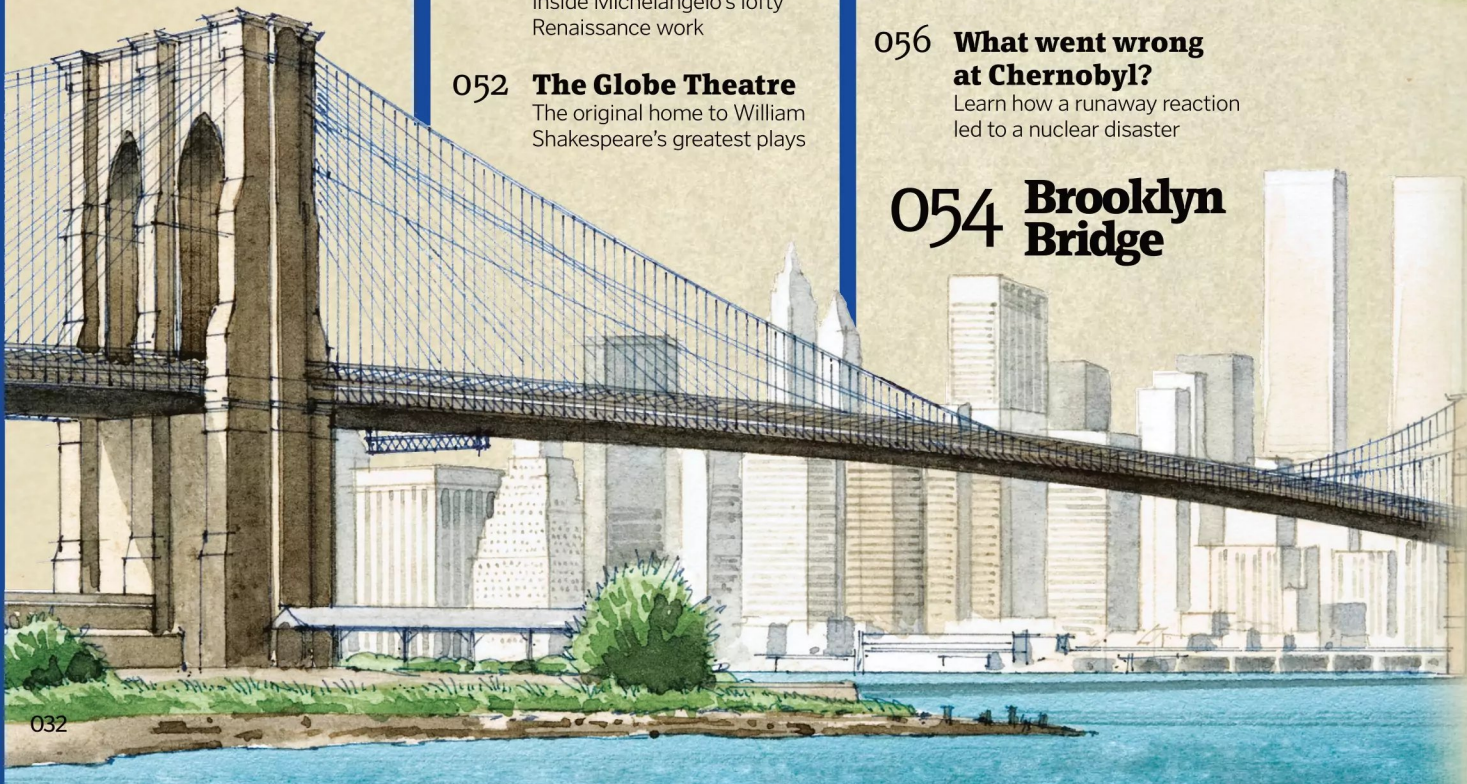
050 How was the Sistine Chapel's ceiling painted?
Inside Michelangelo's lofty Renaissance work

052 The Globe Theatre
The original home to William Shakespeare's greatest plays

054 Brooklyn Bridge
Discover one of New York's most recognisable landmarks

056 What went wrong at Chernobyl?
Learn how a runaway reaction led to a nuclear disaster

054 Brooklyn Bridge





**10 wonders
of the
ancient
world**

034



**Gaze at the
Sistine Chapel**

050



**Explore
Central Park**

046



**040
Inside a
Japanese
castle**



Florence Cathedral

048



10 WONDERS OF THE ANCIENT WORLD

Take a tour of history's greatest human-made landmarks
and discover how they were built



The Pyramids of Giza and the Sphinx

The mystery of ancient Egypt's monumental feat of engineering

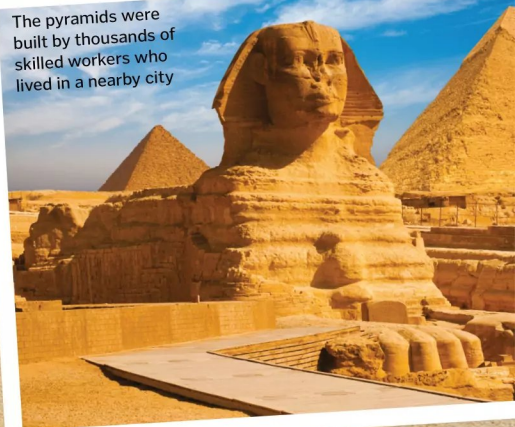
Built between 2589 and 2504 BCE, the three Pyramids of Giza served as extravagant tombs for ancient Egyptian pharaohs, large enough to house everything they would require in the afterlife.

The largest, constructed for the Pharaoh Khufu, consists of 6.5 million tons of stone, some in blocks as heavy as nine tons each.

However, no one quite knows how they were moved into position.

One theory is that a system of sledges, rollers and levers were used to haul the blocks up a slope that was increased in height as the pyramid grew. Meanwhile, the Sphinx, which stands close to the pyramids, was carved out of the limestone bedrock of the Giza Plateau.

The pyramids were built by thousands of skilled workers who lived in a nearby city



The Great Wall of China

Incredible manpower and tasty materials helped construct the world's longest wall

Although the first sections of border walls had been built in the 8th century BCE, it wasn't until 220 BCE that Emperor Qin ordered for them to be joined up as a protective barrier. He set 300,000 soldiers plus many more peasants and prisoners to work constructing the wall from stone, soil, wood and even sticky rice, which was used to help hold the bricks together. The materials were transported to the site by hand or using wheelbarrows, ropes and animals.



Approximately 400,000 workers died during the Great Wall's construction

21,196.18km

Full length of the Great Wall



Equivalent to five times the width of the US

100 million tons

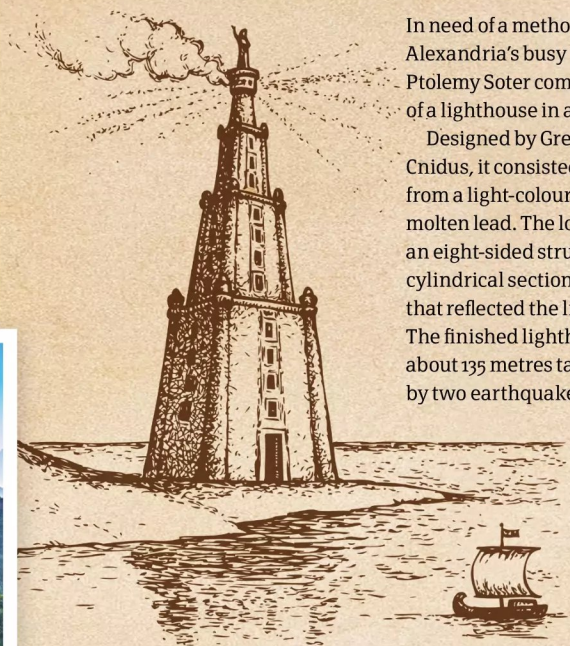
of brick, stone and mud were used to build it

14 metres

The tallest section is equivalent to the height of three buses

Pharos of Alexandria

The design and destruction of the world's first and most famous lighthouse



In need of a method for guiding trade ships into Alexandria's busy harbour, the Egyptian ruler Ptolemy Soter commissioned the construction of a lighthouse in around 280 BCE.

Designed by Greek architect Sostratus of Cnidus, it consisted of three levels, each built from a light-coloured stone and reinforced with molten lead. The lower square level supported an eight-sided structure, on top of which sat a cylindrical section containing a curved mirror that reflected the light from a fire into a beam. The finished lighthouse is thought to have been about 135 metres tall, but was reduced to rubble by two earthquakes in the 14th century.

The Pharos took 12 years and a considerable amount of slave labour to construct

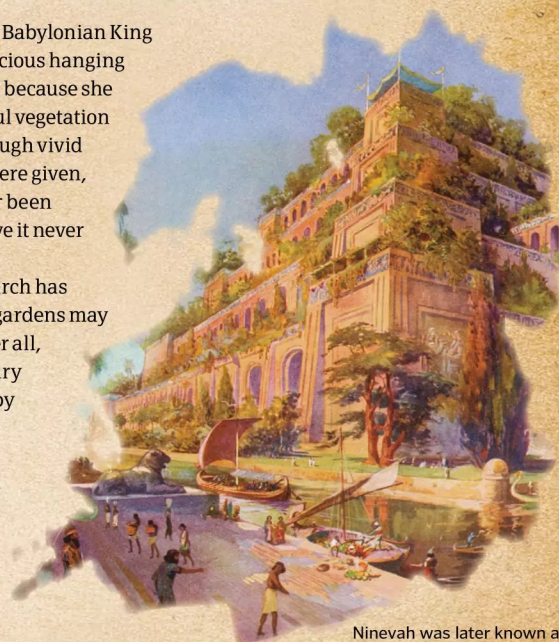
The Hanging Gardens of Babylon

A towering green oasis with a somewhat misleading name

According to ancient sources, Babylonian King Nebuchadnezzar II built a luscious hanging garden for his wife in 600 BCE because she was homesick for the beautiful vegetation of her native Media. But although vivid descriptions of the gardens were given, no physical evidence has ever been found, leading many to believe it never actually existed.

However, a more recent search has discovered that the hanging gardens may not have been in Babylon after all, but were instead built a century earlier in the city of Nineveh by King Sennacherib.

It is thought they were planted on a series of terraces and an Archimedes' screw device was used to douse them with 300 tons of water every day.



Nineveh was later known as New Babylon, which may explain the confusion over the garden's exact location

"The hanging gardens may not have been in Babylon after all"



The Colosseum

Ingenious inventions and designs made the world's largest amphitheatre possible

In 80 BCE, after less than ten years of construction, Rome's enormous entertainment venue was completed. A pioneering feat of engineering, the Colosseum would go on to host bloody gladiator battles, re-enactments and executions for four centuries. The innovative four-tiered design of multiple vaulted arches

provided the structure with plenty of support without adding excess weight and enabled more than 100,000 slaves to build it in simple, standardised parts. The recent invention of concrete also added strength to the Colosseum, helping it hold crowds of more than 50,000 people at a time.

Awnings

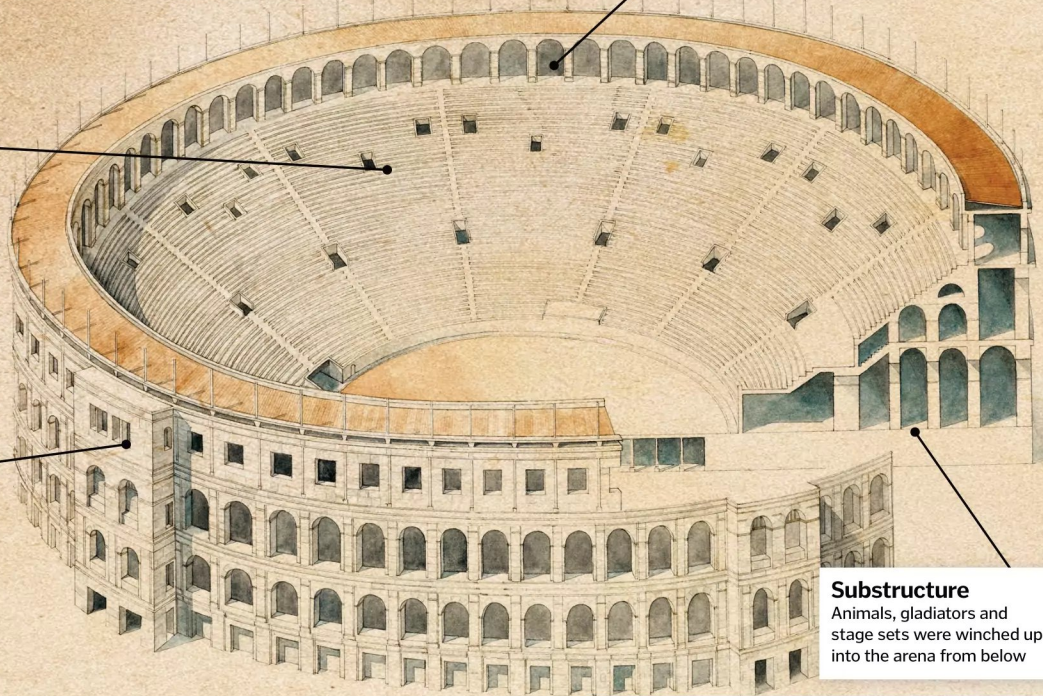
Wooden masts supported awnings that shaded the audience from the Sun

Seating

The tiered seating and elliptical design ensured everyone had a good view

Crowd control

Almost 80 separate arched entrances allowed the crowd to enter and exit with ease



Substructure

Animals, gladiators and stage sets were winched up into the arena from below

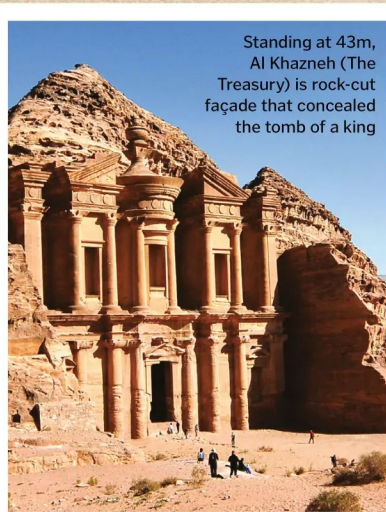
Petra

A unique 'Rose City' carved out of Jordan's desert rocks

Half-built and half-carved from the pink sandstone that inspired its colourful nickname, Petra was established as the capital of the Nabataean Kingdom in 400 BCE. As a busy trading hub, the historic city was once home to around 20,000 people, but getting access to water was difficult in the middle of the desert.

The Nabataeans solved this problem by constructing an elaborate water management system featuring cisterns, reservoirs and dams that conserved seasonal rains.

They chiselled their buildings out of the cliffs by carving steps into the surrounding rock, providing them with safe ledges to work from, and ensured important monuments aligned with the sunrise on winter solstice.



Standing at 43m, Al Khazneh (The Treasury) is rock-cut façade that concealed the tomb of a king

Banaue Rice Terraces

A giant staircase of rice fields built by hand

More than 2,000 years ago, the indigenous people of Ifugao in the Philippines came up with an ingenious method for farming on steep terrain.

With no tools available, they carved a series of terraces out of the mountain, bordering them with walls of mud and stone. They then harvested water from the forests on top of the mountain, flooding the individual fields so that rice could grow. This method of farming and sustaining the terraces has since been passed down through the generations and is still practised today.



The rice terraces can be found in the Cordillera Mountains

Machu Picchu

The amazing engineering found in the Inca's lost city

Meaning 'old mountain' in the native Quechua language, Machu Picchu stands 2,430 metres above sea level in the Peruvian Andes.

Only recently rediscovered in 1911, the city was built by the Inca people in the 15th century and then abandoned 100 years later when their empire was conquered by the Spanish. As the Inca had no written language, there are no records indicating the purpose of the site, but many archaeologists believe it was a royal estate used by leaders.

Set on the steep mountain slopes, the 200 buildings were constructed using a dry-stone technique without mortar. Blocks of granite were precisely cut and tightly slotted together like a jigsaw, leaving cracks so small even a knife could not penetrate them.

"Machu Picchu stands 2,430 metres above sea level in the Peruvian Andes"



Machu Picchu features palaces, plazas, temples, homes and an irrigation system



Easter Island statues

The giant stone heads that required a lot of heavy lifting

In the middle of the Pacific Ocean, almost 900 enormous statues called Moai can be found surrounding the remote Chilean island of Rapa Nui, the original name given to Easter Island by its Polynesian settlers.

The statues were made by the Polynesians sometime between the 12th century and the

17th century, and are thought to represent their dead ancestors.

Despite being carved out of a light, porous rock called tuff, which is formed by compacted volcanic ash, they each weigh several tons, and exactly how they were moved into position still remains a mystery.

The Moai appear in many different stages of completion





Stonehenge

A prehistoric monument helping us to uncover the secrets of the past

In the Wiltshire countryside of England stands one of the most iconic and oldest human-made landmarks in the world.

Built over thousands of years, Stonehenge is the only surviving stone circle of its kind and has become a site of incredible archaeological importance. Although it has revealed a lot about certain practices of the past, the structure is still shrouded in mystery, mainly because we still can't be sure what it was built for.

The most popular theory is that it was a prehistoric temple, as the stones are precisely aligned with the movements of the Sun across the sky, which has special religious significance. What we do know is that its construction began in 3100 BCE, when a large circular ditch was dug using tools made from antlers. Around this time, the site was used for burials; in fact it's the largest late Neolithic cemetery in the UK.

In 2500 BCE, the stones were erected, having been worked into shape and smoothed using sarsen and flint hammerstones, and a few hundred years later were rearranged into their final position. Over the years many of the stones have toppled or been removed, leaving Stonehenge in its current state.

Superhenge

In 2015, scientists found what they thought was another stone monument, five times the size of Stonehenge, buried less than three kilometres away from the iconic landmark. Dubbed a 'superhenge', it was detected using ground-penetrating radar and believed to feature more than 100 stone monoliths.

However, when a dig was conducted, archaeologists instead found a series of deep pits that once held large wooden poles. The site was originally home to the people who built Stonehenge and the poles were erected when they left, perhaps as a memorial. However, they were later removed, and the pits were filled with chalk and covered over with a dirt bank.



The superhenge monument featured wooden poles, not large stones as previously thought

The Henge completed

Discover how Stonehenge might have looked in 2200 BCE

Bluestone

The smaller stones travelled more than 250km via river from the Preseli Hills in southwest Wales and have a blueish tinge when wet

Trilithons

The tall arches were created by fitting a horizontal lintel stone on top of two vertical stones using mortice holes and protruding tenons

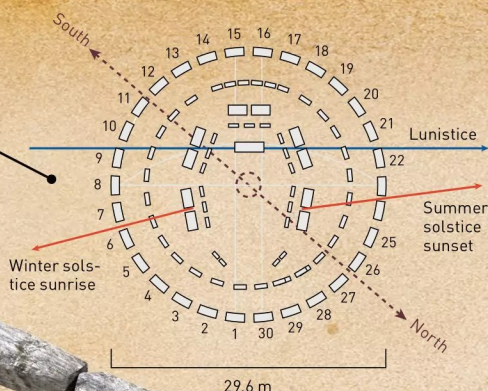
Sarsen stone

These large sandstones came from the Marlborough Downs 32 kilometres away and on average weigh 25 tons each



Alignment

The main axis of the stones line up with the sunrise of the summer solstice and the sunset of the winter solstice



"Stonehenge is the only surviving stone circle of its kind"

Assembling Stonehenge

How might the structure have been put in place with primitive tools?

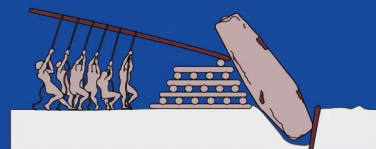
Transportation

The stones were dragged to the site on rollers and sledges, and some even came on rafts down the River Avon.



Positioning

The stones were placed in large holes with sloping sides and lined with wooden stakes at the back.



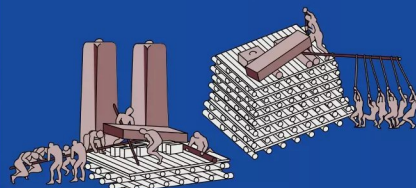
Raising the stones

Ropes, a wooden A-frame and sheer manpower were used to pull the stones upright, then the hole was packed with rubble.



Placing the lintels

Timber platforms were used to lift the horizontal lintels into position before they were placed on top of the upright stones.



Alter stone

Unique to the site, this stone is made from a type of old, red sandstone and comes from the Senni Beds in south Wales

Lintels

The horizontal stones on top of the outer ring were tightly slotted together using tongue and groove joints



Inside a Japanese castle

We find out how Himeji Castle – a 17th-century fortification – has stood firm despite several centuries of conflict and natural disasters

Built on a hill 45 metres above sea level in southern-central Japan, Himeji Castle has survived innumerable feudal battles, sieges, earthquakes and even a WWII bombing. While today it's famed as Japan's largest castle, construction of the original site began in 1333 with the building of a small fort. The fort wasn't turned into a castle stronghold until nearly 250 years later, towards the end of the civil war era. The addition of three moats and dozens of extra buildings – including three large towers and a huge, six-storey main keep, or tenshu – saw the striking white complex become one of the greatest Japanese castles ever built.

As is typical of traditional Japanese architecture, Himeji Castle is an elevated wooden structure featuring ornate tiling and embellishment. As well as gates, walls and other protective fixtures, Himeji and many other castles were equipped with a number of defensive devices to stall advancing foes.

Before they could even think about breaching the defences, the enemy would first have to navigate a frustrating maze of steep, snaking paths laid out around the castle walls. The physically demanding paths that seemed to lead directly to the main keep – but which often led instead to a dead-end – would disorientate and tire invaders. And even if they made it

beyond the perimeter, the home team would then deploy an ingenious bevy of traps designed to outwit and injure the incoming aggressors, including conduits down which they would pour boiling oil or water.

Japan's best-preserved 17th-century castle, Himeji became a UNESCO World Heritage Site in 1993, which is quite remarkable considering what the region has endured, from earthquakes to attacks by US B-29 bombers. Of course, since the demolition of the original 1333 fort, the castle has been rebuilt and remodelled by various rulers and architects, but what's interesting is that neither nature nor conflict has ever managed to get the better of Himeji.

Tour of Himeji Castle

Explore this impressive Japanese castle to find out how it stayed safe under attack

Main keep

Located in a large courtyard the main keep, or tenshu, is the highest tower in the complex. Due to its vulnerable wooden construction, it's covered with thick, fireproof plaster

Hip roof

All reconstructed Japanese castles have an elegant style of roof called irimoya, which features a hip-and-gable structure. Himeji has a rectangular hip roof, whereby the longer two sides slope down toward the walls and then turn up slightly

Gable

The two shorter opposing sides of the rectangle slope too, but they also feature a decorative gable (the triangular bit) part of the way up

Dobei wall

The white dobei walls were constructed by spacing pillars about 1.5m apart and filling in between with a framework of wood and bamboo. Mud and clay were often mixed with a tough kind of Japanese grass called wara to reinforce the walls

Rock chute

Many keeps have ishi-otoshi devices, or rock chutes, protruding from the walls. From here the defence can hurl rocks or boiling liquids like oil onto invaders

Gates

There are many gates among the maze-like courtyards and pathways of Himeji, but all have similar construction, consisting of two columns connected by a crossbeam

Plain interior

While the imposing façade of a Japanese castle like Himeji may look striking, the interiors are far more modest. Rooms are quite dark with little decoration

Loopholes

Japan's castles featured loopholes (like European arrow slits) of various shapes, including circles, squares and triangles, through which they could fire projectiles upon advancing enemies

Bailey

Encircling the main keep is usually a series of three baileys (extra areas of defensive ground). The main, or first, bailey directly encircles the tenshu, while the second bailey surrounds the first, and the third surrounds the second

Neribei wall

Walls of shattered stone, tile and clay brick were mortared and covered in hard plaster at Himeji for quick fortification whenever battle was imminent. These makeshift, earthen walls did not feature the same framework of pillars as dobei walls

The Fogong Temple Pagoda

The oldest wooden pagoda in China today is an architectural marvel by anyone's standards

The pagoda, traditionally a tiered tower built of stone, brick or wood, originated in historic eastern Asia. Usually associated with Buddhism and used for the storing of relics and sacred writings, the pagoda's architectural form has since been adopted by other religions and modified for secular use throughout the world.

The Sakyamuni Pagoda of Fogong Temple forms the central element in a complex of buildings erected by the Chinese Emperor Daozong in 1056. Said to have been built on the site of his family home, the emperor was a devout Buddhist and demonstrated this through the erection of this remarkable wooden, nine-storey structure. Covered with a profusion of carved and painted decoration, the pagoda is supported by 24 exterior and eight interior pillars, and roofed with highly ornate and glazed ceramic tiles.

The pagoda has needed occasional minor repairs over its lifetime and, despite surviving numerous natural disasters, the only serious threat it has faced came during the Second Sino-Japanese War (1937-1945) when Japanese soldiers raked the structure with small-arms fire. Today, the Fogong Temple Pagoda is a popular tourist attraction rather than a religious site, but its cultural significance is recognised in both China and beyond.

Built to last

During the first 50 years of its existence, the Fogong Pagoda survived seven earthquakes. The reason for the building's resilience is both its design and building material. The key to its wooden construction is found in its slanting pillars, which act as both external and internal buttresses, and the 54 kinds of bracket arms used to create it. These interlocking sets of brackets, called 'dougong' in Chinese (literally 'cap and block'), provide increased support for the weight of the horizontal beams that span the pagoda's pillars by transferring the weight over a larger area.

In this way a building consisting of many storeys may be constructed. Most importantly the use of multiple bracket arms allows structures to be elastic, which is how the Sakyamuni Pagoda has repeatedly withstood earthquakes that have flattened many of its neighbours.

Anatomy of a pagoda

Examine the Sakyamuni Pagoda of Fogong Temple from top to bottom

Steeple

The steeple which surmounts the pagoda's roof is 10m tall and serves as a lightning rod

Statue of the Buddha

This statue, surrounded by images of other Buddhist deities, is the pagoda's principal devotional focus

Foundation

The stone platform which supports the pagoda is 4m high and provides a stable foundation

China is hoping for the Sakyamuni Pagoda to be included on the UNESCO list of cultural relics and is currently on a tentative list

Mezzanine

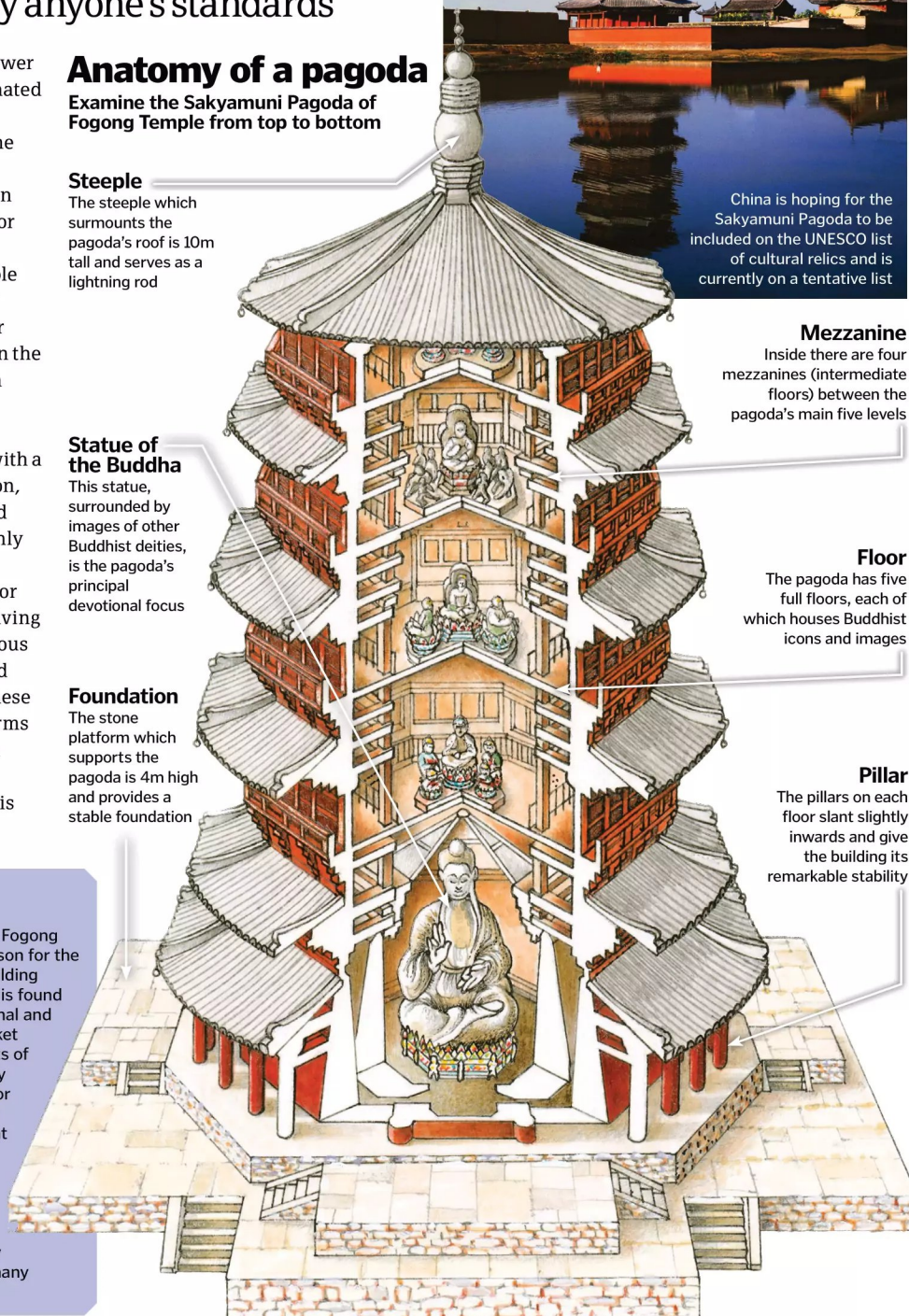
Inside there are four mezzanines (intermediate floors) between the pagoda's main five levels

Floor

The pagoda has five full floors, each of which houses Buddhist icons and images

Pillar

The pillars on each floor slant slightly inwards and give the building its remarkable stability





The Washington Monument

Inside the US capital's iconic marble obelisk that commemorates the achievements of the nation's first president

Standing tall above the US' capital city, the Washington Monument is a constant reminder of the legacy of founding father George Washington. As the first president of the United States, he is one of the most important figures in the nation's history.

The 169-metre-high monument was designed by Robert Mills in the shape of an Ancient Egyptian obelisk. It started out as a private project that was financed by the Washington National Monument Society, with Mills contributing the chosen design. A crowd of around 20,000 Americans gathered to watch as the first cornerstone was laid on 4 July 1848.

However, the project soon ran into issues. In 1854, the society was declared bankrupt, and a year later Mills died. Construction was halted throughout the US Civil War and was only restarted in 1876. The US Congress took control over construction and things ran much more smoothly. The monument was finally completed in 1884 and eventually opened to the public four years later.

The monument stands south of the White House and west of the Capitol Building

Dimensions

Ten times as tall as it is wide, the monument's height was reduced to 169m from the original planned size of 182m

Inside the Washington Monument

Take a tour of one of the US capital's most iconic structures

Construction

In the later phases of construction, a steam-powered lift carried stones up the iron scaffold that the masons worked from

Marble sources

Stone from three different quarries was used throughout construction, leaving a visible divide in the marble shades

Commemorative stones

Lining the stairwell, there are 193 stones that were presented by cities and people around the world

Steam-powered lift

In 1888, a steam-powered lift was installed that could take visitors to the observation deck in 12 minutes. The first electric lift was added in 1901, and has been updated several times since

Iron staircase

Inside the tower is an 897-step, 50-flight spiral staircase that takes about 20 minutes to ascend

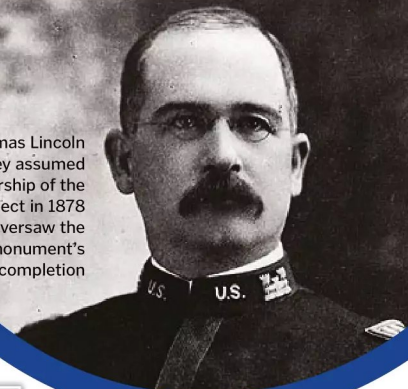
Foundations

Concrete was added to the monument's foundations part way through construction, as the original material used was too weak

Aluminium tip

At the top of the monument is an aluminium cap, originally intended to serve as a lightning rod

Thomas Lincoln Casey assumed leadership of the project in 1878 and oversaw the monument's completion



Windmills

Find out how these towers have helped harness wind power throughout history

It is thought that the windmill was invented around 1,500 years ago. Historians are still unsure exactly where the first one was constructed, but it is believed that it was either in ancient China or ancient Persia.

The first windmill mechanisms used millstones powered by sails that rotated a drive shaft to pump water or mill cereal. They became an integral part of ancient agriculture and were also used in sawmills and to help with irrigation and drainage.

The first windmills turned on a vertical axis. Later versions revolved horizontally, which was found to be a more efficient process. Tail fans were also added to later models to automatically move the sails in the direction the wind was blowing.

To remedy variable wind speeds, modern windmills utilise overspeed controls to turn the mechanism away from the wind if the gusts are too powerful for the sails to handle. Before the invention of windmills, grinding corn, pumping water and cutting lumber was done by hand. Windmills sped up and increased the efficiency of the process significantly, having a dramatic impact on the world's agriculture and economy.

Inside a thatched smock mill

How a windmill uses wind power to mill grain

1 Revolving cap

The cap of the mill rotates to face whichever way the wind is blowing, increasing rotation speed

2 Sails

The lattice sails move anti-clockwise, turning the mechanism inside in a clockwise direction

3 Brake wheel

The sails catch the wind and turn the horizontal wind shaft, which in turn revolves the largest cog, the drive gear

4 Dual millstones

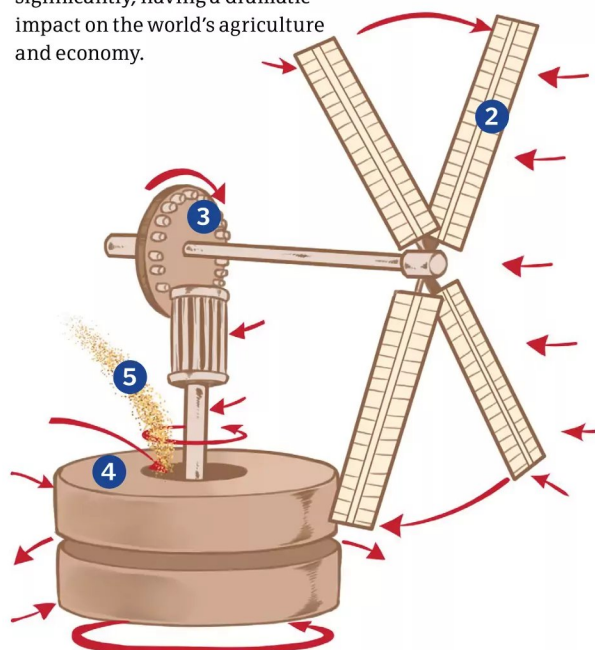
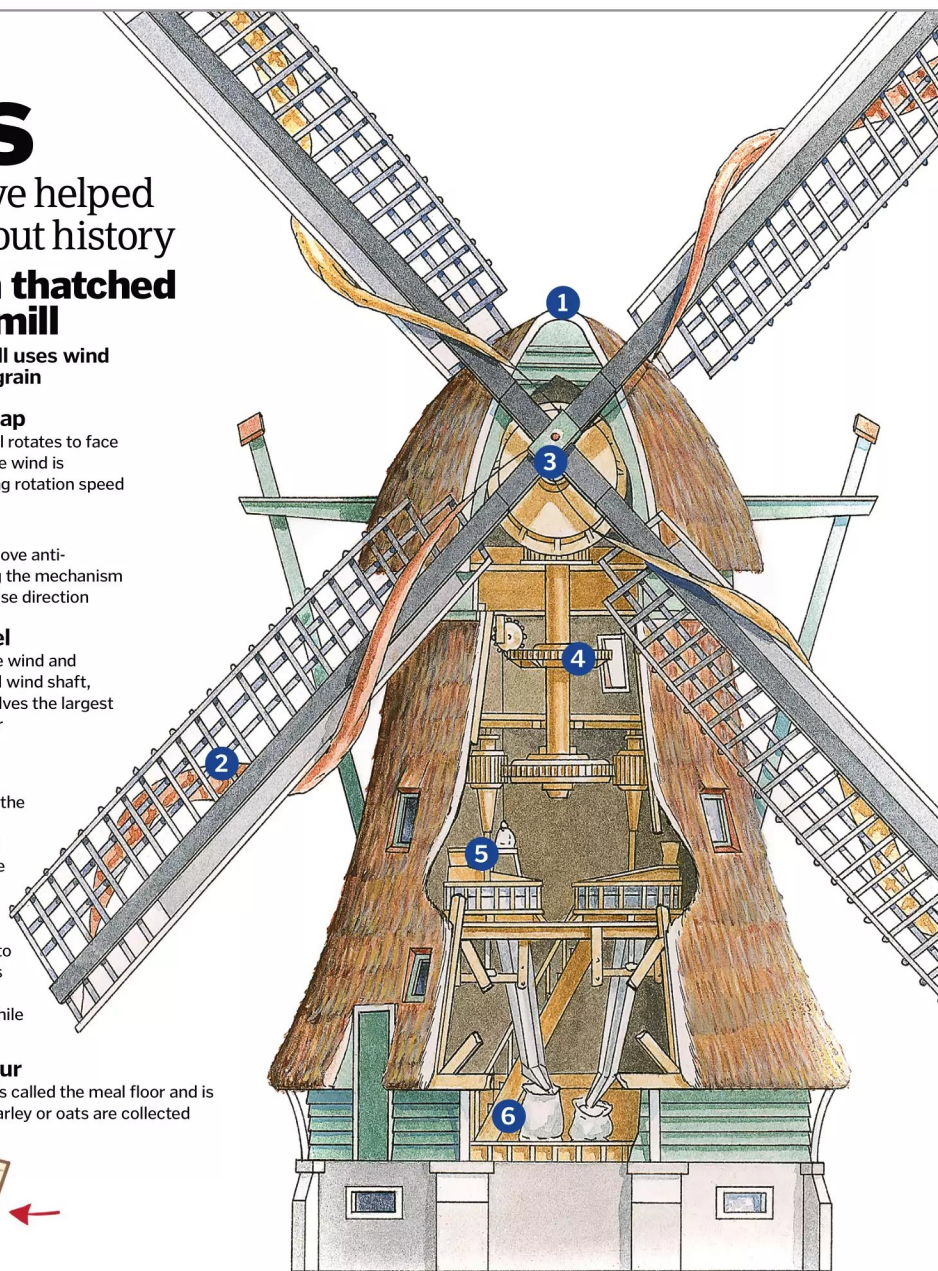
The movement of the drive gear turns a vertical shaft that powers a millstone

5 Feeding the grain

The grain is fed into the two millstones by a hopper. One millstone is still while the other rotates

6 Grain to flour

The bottom floor is called the meal floor and is where the flour, barley or oats are collected



Why did windmills fall out of use?

The use of windmills has declined in the modern world. This is primarily down to the introduction of steam power in the Industrial Revolution. This reduction only became even greater than before when electricity came into common use. Today, windmills are mainly listed as heritage sites or have fallen into disrepair. Rather than grinding grain, today's windmills take the form of wind turbines and are one of the world's leading renewable energy sources. Moreover, simple wind pumps have been around since ancient times and are still commonly used both for draining wetlands and obtaining groundwater in areas short on drinking water.





Edinburgh Castle's story

The scene of numerous sieges, Edinburgh Castle still stands proudly today as a symbol of military might

Sitting proudly atop of Castle Rock (a 700-million-year-old extinct volcano), Edinburgh Castle is one of the most iconic battlements on Earth and Scotland's second most visited tourist attraction.

Once the site of a fortification known as the 'Castle of the Maidens', the edifice that now stands on Castle Rock was constructed in the 12th century by David I, Prince of the Cumbrians and later King of the Scots from 1124–1153.

At over 131 metres above sea level and featuring looming sheer walls, the castle could not be stormed from any direction save the east. Yet despite posing a formidable obstacle to anyone wishing to take it, opponents knew that control of the castle meant control of the city.

Witness to numerous bloody encounters, the first major battle fought at Edinburgh Castle unfolded in 1296 following King Edward I of England's invasion of Scotland in March of that year, an incursion that sparked the First War of Scottish Independence. Following a three-day bombardment, the garrison inside the castle surrendered, but England's hold upon this

strategically vital position would be anything but consistent in the centuries to follow.

Following the Scottish Wars for Independence, King David II, son of the fearsome warrior Robert the Bruce, had to contend with the damage inflicted upon Edinburgh Castle during the conflict. Eager to repair the broken fortress, King David oversaw a period of restoration that included the initial work to construct David's Tower, which was later replaced by the Half Moon Battery.

In the succeeding years Edinburgh Castle would witness further attempts by both the English and the Scots to wrest control of the castle and suffer the damage that such brutal clashes often caused.

Predominantly used to house prisoners of war captured during England's many foreign campaigns in the 18th and 19th centuries, the castle became a national monument in 1814. With over 1 million visitors a year, today Edinburgh Castle is a crucial part of the city's £1.6 billion tourist industry.

Beyond the walls

From cannons to crown jewels, Edinburgh Castle is home to much of Scotland's history

A key leader in the Scottish Wars of Independence, a statue of William Wallace stands before the castle gates



Great Hall

Constructed during the reign of King James IV, the Great Hall is thought to have been used by the Scottish Parliament

National War Memorial

Built to commemorate Scotland's fallen during WWI, the War Memorial was first opened in 1927. Entrance is free to the public

Royal Palace

Once used as royal apartments by the Stewart monarchy, the Royal Palace now houses the Stone of Scone

Half Moon Battery

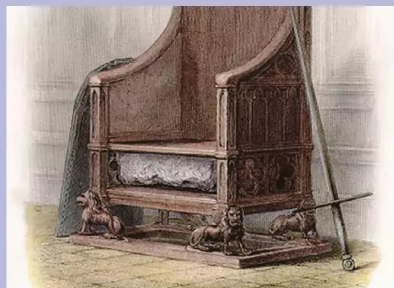
Built above the remains of David's Tower, this battery was finished in 1588. It was enormous by the standards of its time

The Stone of Scone

Also known as the Stone of Destiny, this 66-centimetre-long block of red sandstone weighs in at around 152 kilograms and has seated numerous monarchs over the centuries.

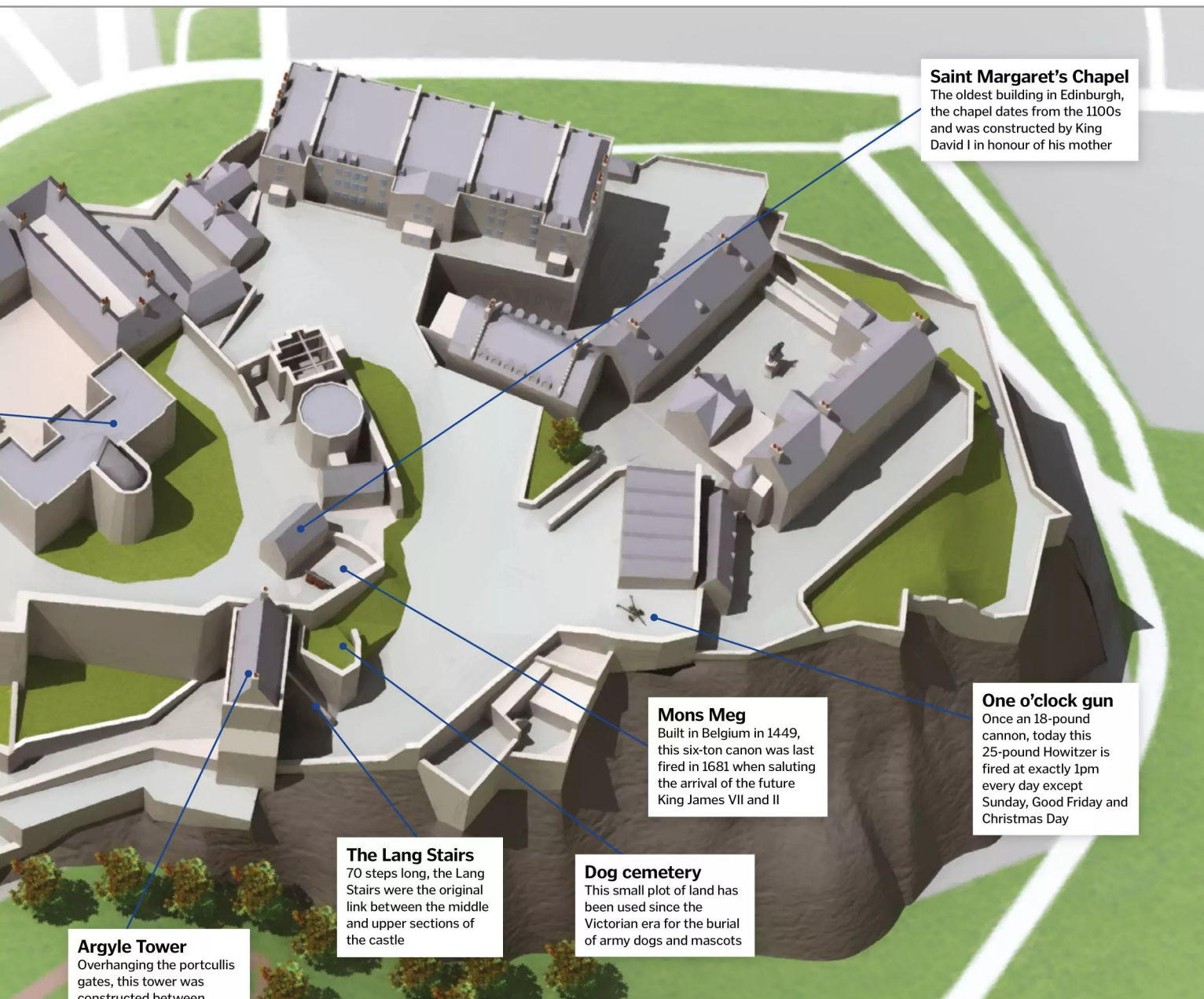
Thought to have originated in Ireland, the stone was transported from Scotland to England in 1296 to be placed within the throne of King Edward I. It would reside in England for approximately 654 years until its illegal removal by four Scottish students in 1950.

Attempting to return it to Scotland, the students accidentally broke the stone in two. It was found in 1951 and finally returned to its homeland. Residing today in the Crown Room of Edinburgh Castle, it will only leave Scotland when there is another royal coronation.



The Stone of Scone set into the Coronation Chair in Westminster, London, in 1855

"Control of the castle meant control of the city"



Saint Margaret's Chapel

The oldest building in Edinburgh, the chapel dates from the 1100s and was constructed by King David I in honour of his mother

Mons Meg

Built in Belgium in 1449, this six-ton canon was last fired in 1681 when saluting the arrival of the future King James VII and II

One o'clock gun

Once an 18-pound cannon, today this 25-pound Howitzer is fired at exactly 1pm every day except Sunday, Good Friday and Christmas Day

The Lang Stairs

70 steps long, the Lang Stairs were the original link between the middle and upper sections of the castle

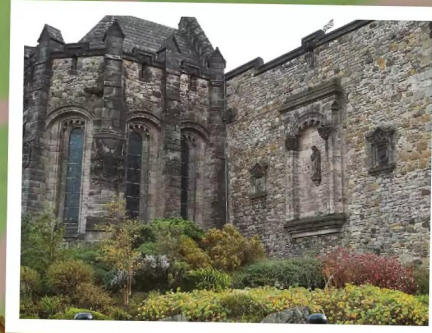
Dog cemetery

This small plot of land has been used since the Victorian era for the burial of army dogs and mascots

Argyle Tower

Overhanging the portcullis gates, this tower was constructed between 1886–1887 and named after the 9th Earl of Argyll

Despite its royal heritage, Saint Margaret's Chapel was used to store gunpowder in the 16th century

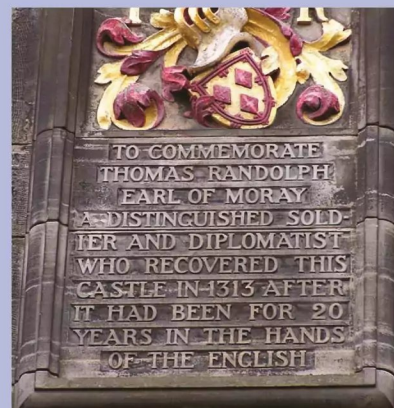


Thomas Randolph, captor of the castle

Born in 1278, Thomas Randolph, 1st Earl of Moray was the nephew of Robert the Bruce and a key figure in the Wars for Independence.

Supportive of his uncle's rebellion in 1306, Randolph was imprisoned by the English following the Battle of Methven in that same year and fought for King Edward I until he was recaptured by the Scots in 1308.

Installed as Earl of Moray in 1312, Randolph would repay his uncle's kindness in 1314 when he led a band of 20 men on a daring raid to retake Edinburgh Castle. Scaling the seemingly impassable walls, Randolph's audacious plan worked as the English were completely taken by surprise. With the castle back in Scottish hands, Randolph went on to fight courageously in the crushing victory over the English at Bannockburn three months later.



An inscription commemorating Randolph's raid. The date is incorrect due to calendar changes



The history of Central Park

How did such a huge area of New York City become a green space?

If you look at the huge, sprawling space in New York that is occupied by Central Park, you probably won't realise quite how much it has changed since it was first created. The land, acquired by the City of New York in 1853, was over 700 acres of mostly barren swampland.

The story of Central Park began in the 1840s, when wealthy merchants and landowners urged the state to consider a public ground that would compare to parks in London and Paris. After many debates over the size and location of the park, a huge area in central Manhattan was chosen. In all, 9,792 standard 25 x 100-foot (7.6 x 30.5-metre) building plots were acquired for a grand total of over \$5 million. At the time, this

area was distant from the built-up area of the city, which was mainly in south Manhattan. The land chosen was uneven terrain, with rocky outcrops and swamps dotted around, making it undesirable for building. However, that didn't mean that there was nobody living there; in fact, around 1,600 poor residents were displaced by the project, including a stable African-American settlement in Seneca Village.

Converting this space into the beautiful park you see today was an enormous task. In 1858, a landscape design competition was held to choose the style and layout of the park, and work

began soon after. It's estimated that 20,000 workers were involved in reshaping the land, and 260 tons of gunpowder was used to blast through the rock on site. Over 270,000 trees and shrubs were planted in the park, and a new reservoir was constructed. In the winter of 1859 the first part of the park opened to the public.

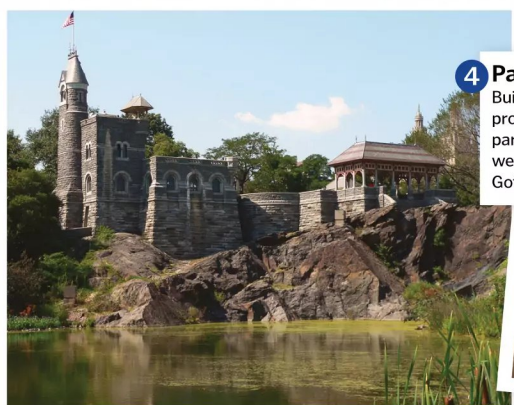
Construction continued for many years, and the cost of building the park rose to almost \$4 million. In 1871, the now famous Zoo was given permanent quarters, and quickly became the park's most popular feature.

Planning Central Park

Building this vast public space was a huge job



1 Walk past an Egyptian
This genuine ancient Egyptian obelisk is one of a pair (the other is in London) and is the oldest outdoor monument in New York City



4 Panoramic view
Built in 1869, Belvedere Castle provides excellent views of the park, and also houses a weather station. It is a mix of Gothic and Romanesque style



3 Bethesda Terrace
This terrace was one of the first structures built in Central Park. The lower terrace features the beautiful Bethesda Fountain



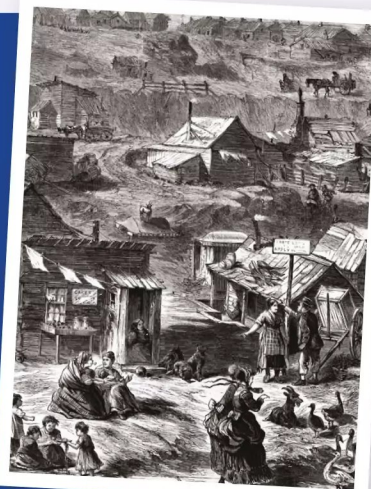


The park stretches from 59th Street all the way to 110th Street

The history of Seneca Village

Seneca Village is an area within Central Park that looks like any other, but there is a lot of history hidden in the land. Nearly 200 years ago, in 1825, Andrew Williams and Epiphany Davis became the first African-Americans to purchase land in Seneca Village. Within four years, nine substantial houses had been built in the area, which was near the Hudson River (for fishing) and a natural spring.

By 1855 a census indicated that Seneca Village was home to around 250 people in 70 houses. However, when the plans for Central Park were made, the New York State legislature used a rule called 'eminent domain' to take this private land for public use, and compensate the owners in return. The community was forced to leave and the houses were demolished to build the park. Modern excavations in the area are now uncovering artefacts and stone foundations that tell us more about how the community lived.



Seneca Village was home to African-Americans and European immigrants

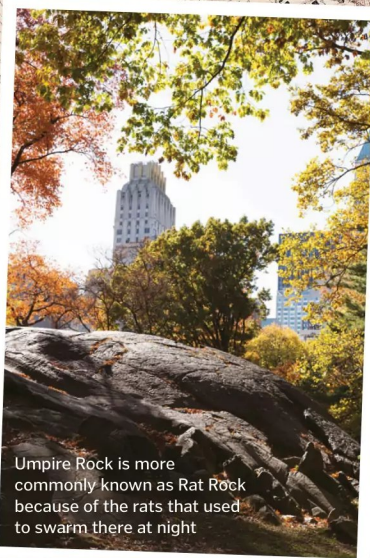
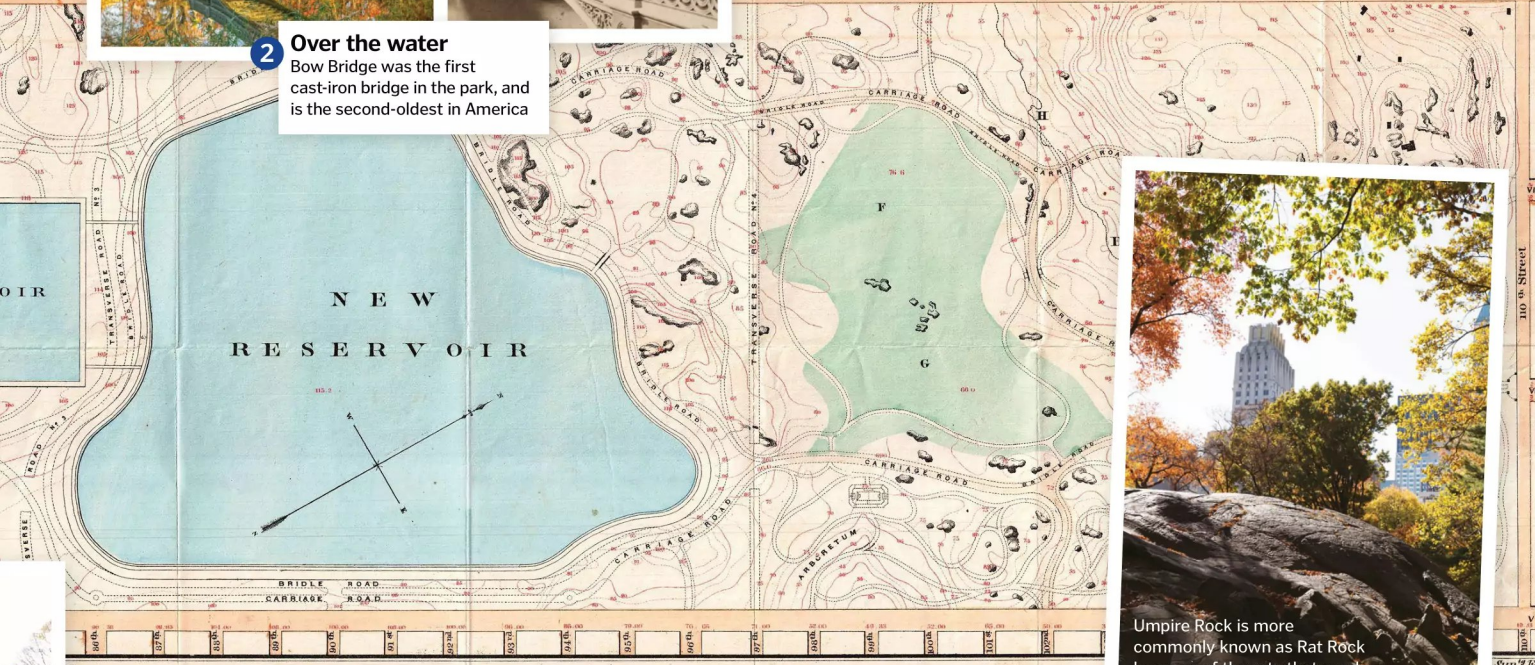
"Creating the beautiful park you see today was an enormous task"



2 Over the water
Bow Bridge was the first cast-iron bridge in the park, and is the second-oldest in America



TRAIL
Park up to
THE INCH
AVENUE



Umpire Rock is more commonly known as Rat Rock because of the rats that used to swarm there at night

Five Central Park facts

Real history

Umpire Rock is one of several points where the bedrock of New York City is exposed. The rock was formed hundreds of millions of years ago during the Paleozoic era.

Sheep Meadow

The iconic Sheep Meadow really did use to be home to sheep. They were kept at the Tavern on the Green, and were let out to graze twice daily.

No racing!

The curved roads within the park were designed to stop people racing their carts and injuring people. Now people race their bikes along the paths instead!

No picnics!

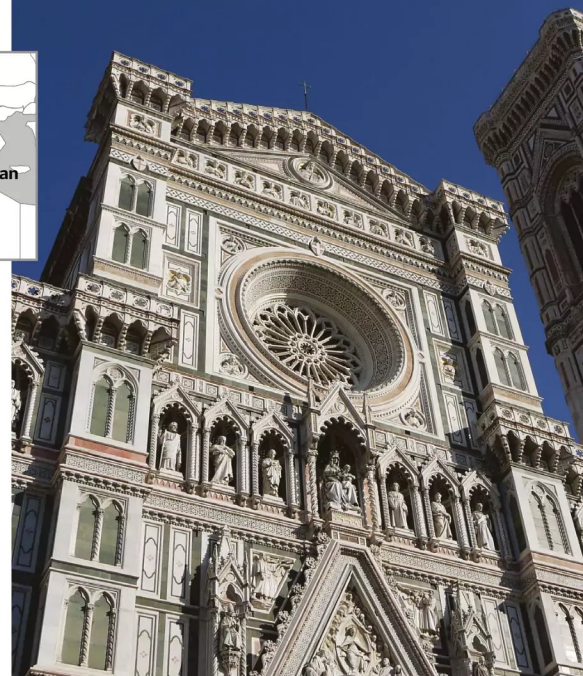
Strict rules in the first decade of the park's existence meant that group picnics were prohibited within the park, which discouraged a number of less wealthy families from visiting.

No ball games!

When the park was first completed, schoolboys were only allowed to play ball games on the lawns if they had a note signed by their principal.

**The statistics...****Florence Cathedral****Height:** 114.5m (375ft)**Length:** 153m (502ft)**Width:** 38m (125ft)**Cost:** At least £500m (\$802m)**Date of construction:**
1296-1436**Architect:**

At least 11 different architects



Florence Cathedral

Crowned with the largest masonry dome in the world, Florence Duomo is a Renaissance masterpiece

Popularly called the Duomo, Florence Cathedral's name is derived from the Latin 'domus dei' – the House of God – and is dedicated to the Virgin Mary Santa Maria del Fiore (St Mary of the Flower). The present building was started in 1296 and is the third cathedral to stand on the site. Taking 140 years to build, the original plan was only changed once during construction when the eastern half of the cathedral was massively expanded to allow for the now iconic dome. Work on this extraordinary structure began in 1420 and was completed in just 16 years. Higher and wider than any previously built, the octagonal dome was constructed without using a temporary wooden supporting frame. Consisting of a double shell made of sandstone, marble and brick, the base of the dome is about 52 metres (171 feet) above the ground and has a staggering 44-metre (144-foot) diameter.

The cathedral's exterior walls are faced in alternate vertical and horizontal bands of coloured marble – white from Carrara, green from Prato and red from Siena. Despite the many architects to work on it the building retains a remarkable architectural and aesthetic cohesion. The interior is sparsely decorated, but contains a number of major Renaissance artworks and 44 stained-glass windows – in fact, the largest expanse of glass installed during 14th and 15th century Italy.

Above the main door is the basilica's one-handed liturgical clock, which shows all 24 hours. Erected in 1443, it is still working today. The largest cathedral in Europe when it was built, it has become symbolic of Florence and its dome is instantly recognised around the globe. Such is the Duomo's cultural importance that the cathedral complex was designated a UNESCO World Heritage site in 1982.

A tour of the basilica

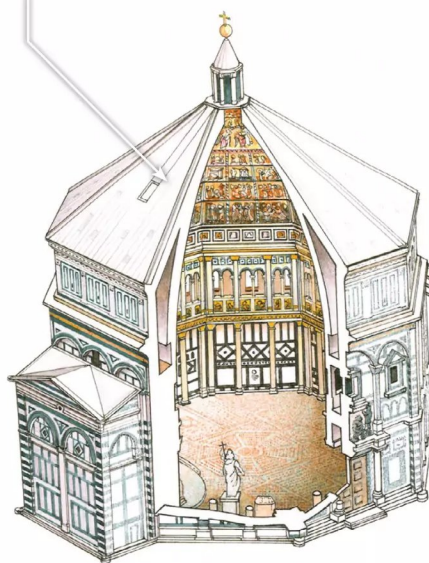
It looks deceptively simple but Florence Cathedral boasts some very sophisticated architecture

Baptistry

This octagonal building's eastern doors are a Renaissance masterpiece by the sculptor Lorenzo Ghiberti. Its panels illustrate scenes from the Old Testament

West façade

This was the last part of the cathedral to be completed between 1876-1887 to the designs of architect Emilio de Fabris





Lantern

A stone lantern crowns the dome and is surmounted by a gilt-copper cross and ball containing holy relics

Dome interior

The interior surface of the dome is covered in an enormous fresco depicting The Last Judgement, painted by Giorgio Vasari

Campanile

Considered by many to be Italy's most beautiful bell tower, the top of the campanile can be reached by climbing 414 steps

Dome

The double-skinned dome comprises more than 4 million bricks and over 37,000 tons of material

The Baptistry of St John

This octagonal building stands slightly to the west of the cathedral. Built to house the font in which all Christians in Florence were baptised, it was constructed between 1059 and 1128. The baptistry is famous for three sets of artistically important bronze doors. The eastern pair, facing the cathedral, so impressed Michelangelo that he called them the 'Gates of Paradise'. Made of sandstone and faced with marble incorporating many reused fragments of Roman buildings, the exterior features many sculptural groups and two massive porphyry columns.

The interior of the baptistry is clad in marble, while the inside of the dome which roofs the structure is inlaid with magnificent gold mosaics. The floor is covered in marble featuring a design based on the zodiac. Unusually, the baptistry also houses a number of tombs, including that of the antipope John XXIII which is considered a significant early-Renaissance sculptural work.

Giotto's campanile

The campanile, or bell tower, was designed by the celebrated painter Giotto di Bondone and it houses seven bells. Standing next to the cathedral, it is built from the same coloured marbles and so blends in well with its neighbour. The tower is square in plan with sides measuring 15 metres (47 feet) and it soars 87 metres (278 feet) high. Embraced by polygonal buttresses at its corners, it's divided into five separate levels – the upper three of which contain windows. Each of the three top levels is larger than the one below it in every dimension. These differences in size counter the effect of perspective so when viewed from below, the three top levels of the tower look equal in size. Although Giotto originally intended the campanile to be surmounted by a tall spire, after his death it was decided to build a large projecting terrace instead, which lends the tower a dramatic 'broken off' look.



© Thinkstock

Transept

The cathedral's small transepts (the 'cross arms') house a number of chapels, tombs and major sculptural works

Crypt

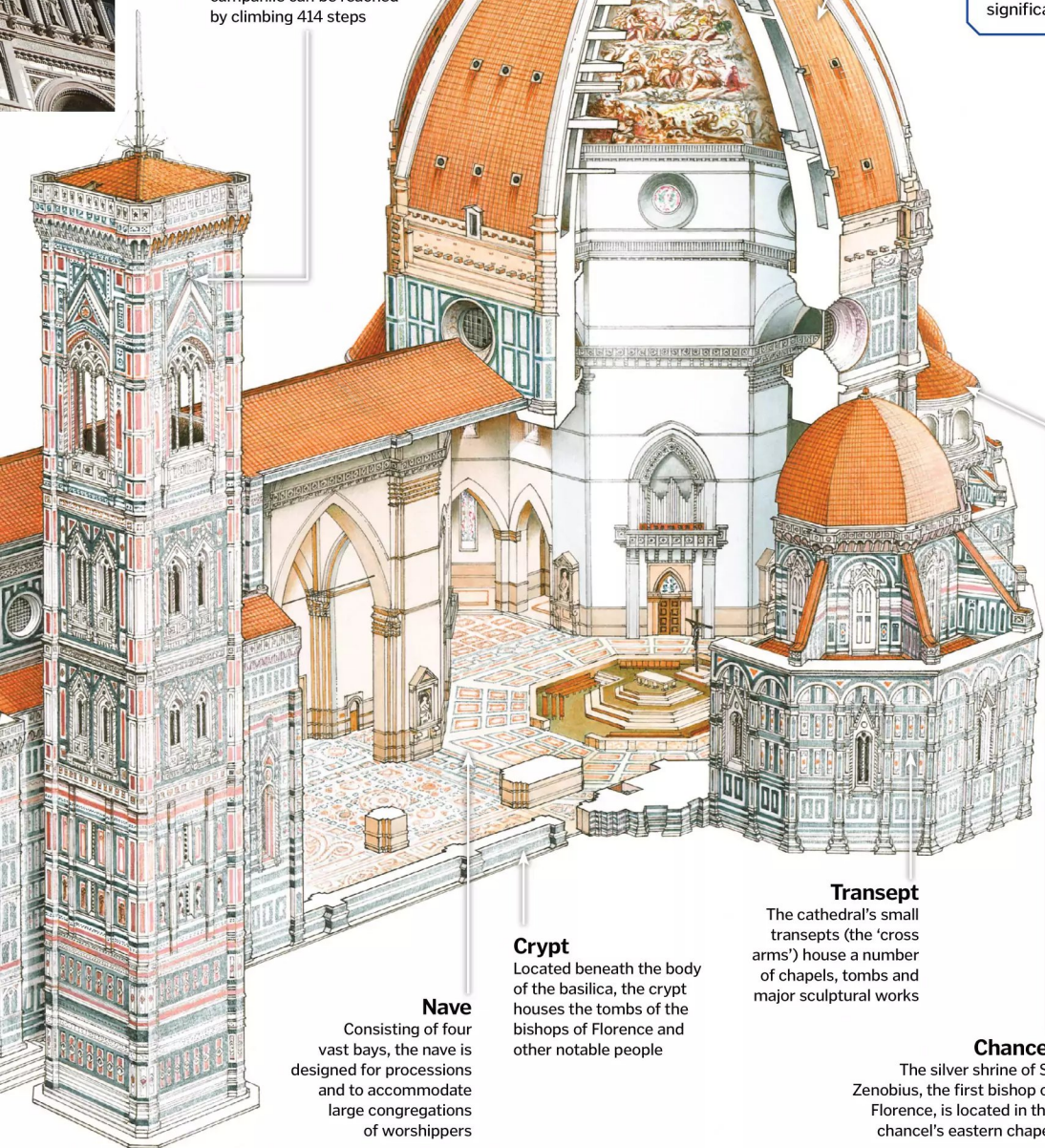
Located beneath the body of the basilica, the crypt houses the tombs of the bishops of Florence and other notable people

Nave

Consisting of four vast bays, the nave is designed for processions and to accommodate large congregations of worshippers

Chancel

The silver shrine of St Zenobius, the first bishop of Florence, is located in the chancel's eastern chapel





How was the Sistine Chapel's ceiling painted?

Explore the tools and techniques behind Michelangelo's lofty Renaissance masterpiece

In painting the Sistine Chapel's ceiling in the early part of the 16th century, Michelangelo had to overcome a number of daunting hurdles. The first comes directly from the physical properties of the ceiling, as it is a barrel vault, which is a curved surface. To make it more difficult still, that barrel vault is intersected with smaller vaults positioned over the windows. As such there are no flat surfaces anywhere except around the windows, where the artist also painted a series of half-moon-shaped lunettes. As a result, even prior to picking up a paintbrush Michelangelo had to first work out how to create realistic portrayals of human figures in proper proportion and in motion on these wildly uneven surfaces. His ability to pull this off is testament to his immense artistic skill.

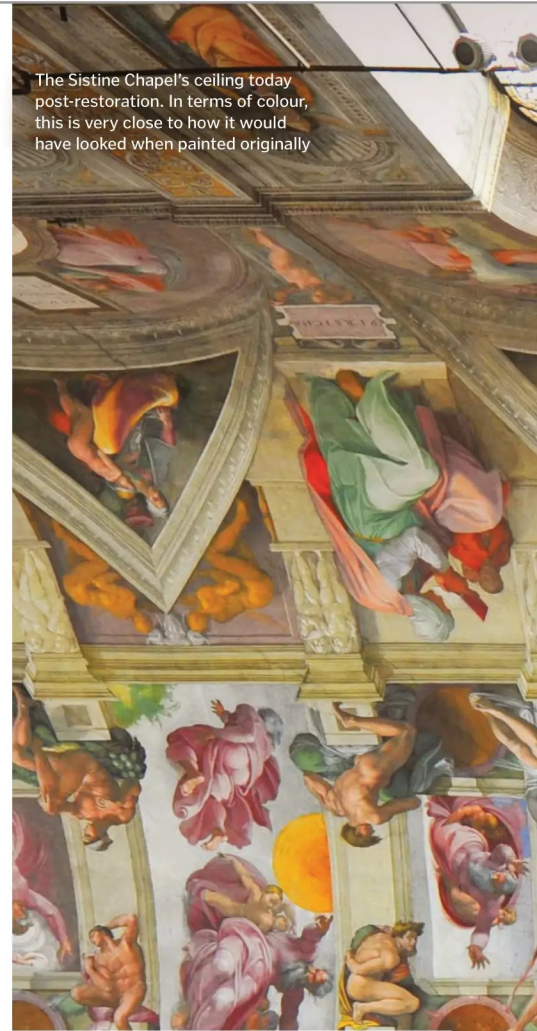
Another major challenge in painting the Sistine Chapel's ceiling was actually getting up there, as it is 20 metres above the floor. Fortunately, a conservation campaign that started in the Eighties revealed the method Michelangelo employed to reach such heights: he constructed a complex scaffold. The scaffold consisted of a truss bridge that spanned across the vault and ran on rails that were at a 90-degree angle to the walls. This permitted Michelangelo to access all areas of the ceiling as the scaffolding could be moved along the rails – it was only ever covering a quarter of the vault at any one time, as he needed ambient light from the windows to paint. Interestingly, the holes that were made to support this structure can still be seen in the walls to this day.

The third problem Michelangelo had to tackle was how to lay out the sketch lines for the entire ceiling. He did this by dividing the vault into various units by stretching chalked strings from one end of the chapel to the other (with help from assistants), before snapping them against the prepared plaster. In doing this, he laid out the linear structure of all the architecture, which is consistent throughout.

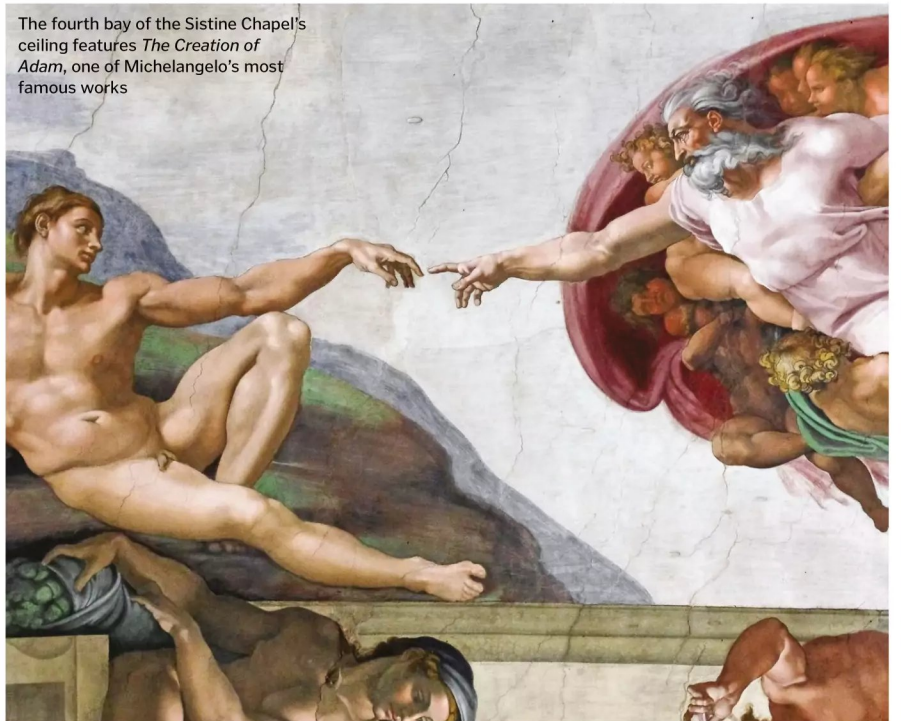
The last major obstacle that Michelangelo faced was the sheer scale of the project, which incredibly only took four years to complete. Painting the ceiling was a massive logistical undertaking and so he invited some of his friends from Florence to Rome to aid him.

As well as painting some of the recurring elements, such as columns and statues, these assistants helped him to build the scaffolding and mix/prepare the plaster, as well as lending a hand with the manufacture of paints, the trimming of paintbrushes and the sketching of full-sized drawings on paper for transferral onto the vault. This latter process involved the paper sketch being pressed against the ceiling, pricked with small holes around the outlines and then covered with black chalk dust to produce a dotted outline on the plaster.

The Sistine Chapel's ceiling today post-restoration. In terms of colour, this is very close to how it would have looked when painted originally



The fourth bay of the Sistine Chapel's ceiling features *The Creation of Adam*, one of Michelangelo's most famous works







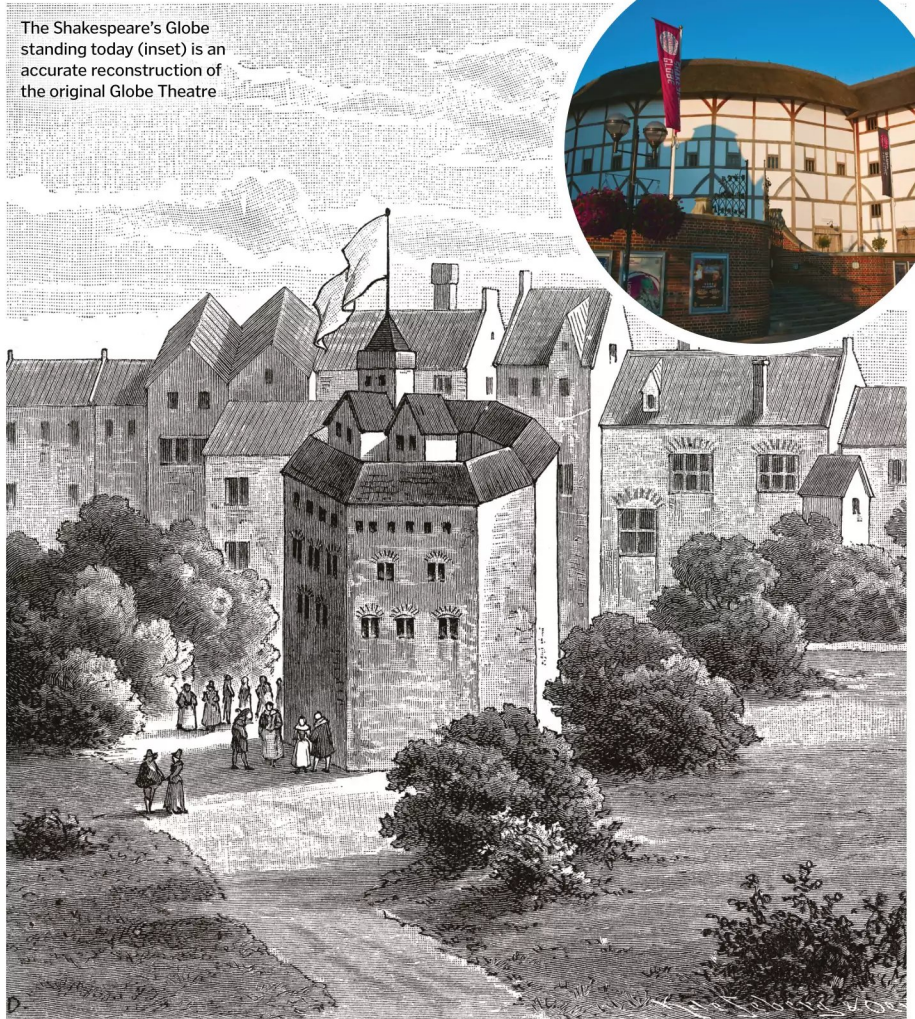
The Globe Theatre's story

The most famous and historic theatre in Britain – if not the world – the Globe was the original home to William Shakespeare's greatest plays

The Globe Theatre was an Elizabethan-era playhouse part-owned and made famous by the great playwright William Shakespeare. Built from the remains of an existing theatre in Shoreditch, London, made by English actor and theatre owner Richard Burbage and his brother Cuthbert, the Globe was constructed out of timber over just a few months in 1599. It was a very attractive and imposing theatre at its time. The playhouse became the home of the Lord Chamberlain's Men, a troupe of which Shakespeare and the Burbages were members. The group went on to perform many of the Bard's most famous plays there. Reportedly, the first performance was *Julius Caesar*, with subsequent famous plays such as *Richard II*, *Romeo And Juliet* and *A Winter's Tale* also shown there.

The Globe proved a great success, with its 3,000 capacity frequently tested to the limit, both in the cheap standing-only pit area as well as in the more prestigious tiered seating located around the inner walls. Unfortunately, however, on 29 June 1613 during a performance of *Henry VIII*, a theatrical cannon misfired and ignited the wooden beam and thatch roof, leading to the entire building burning down. Luckily, the success of the Globe's owners and its performances resulted in the theatre being rebuilt again in 1614, with the new playhouse continuing to host many acting troupes well after Shakespeare's death in 1616. In fact, it was not until 1642 that the theatre was closed down – a casualty of the English Civil War. Its legacy, however, is just as eternal as the plays written by the Bard himself.

The Shakespeare's Globe standing today (inset) is an accurate reconstruction of the original Globe Theatre



The Globe over time

Check out some of the main events in the theatre's history now

1599: Grand opening

The Globe Theatre is opened on Bankside, London.

1601: *Richard II* runs

Shakespeare's acting troupe, the Lord Chamberlain's Men, are commissioned to stage *Richard II*.

1608: Blackfriars bought

The Globe's co-owner, Richard Burbage, acquires the lease for the Blackfriars Theatre, which is then used for winter performances.

1614: Globe rebuilt

Following a disastrous fire that burned down the Globe, it is rebuilt a year later on the original foundations.

1597: Resurrection

An accurate reconstruction of the Globe is built near to the site of the original building. It stages Shakespeare's works and is a popular tourist attraction to this day.

1644: Globe destroyed

The theatre is razed to the ground again – this time by order of the Puritans. Landowner Sir Matthew Brend builds tenement houses on the site in its place.

1642: Plays suppressed

In the English Civil War, Parliament issues an ordinance that forbids all stage plays. The Globe is shut down.

1616: Mortal coil

William Shakespeare dies aged 52 in Stratford-upon-Avon, where he is buried in the Holy Trinity Church.

A modern-day Globe

Theatre fans today can visit the modern reconstruction of the Globe. It was nevertheless made to be historically accurate, consulting the plans, construction methods and materials of the 1599 original, albeit with modern safety standards in mind. Shakespeare's Globe is built from 100 per cent English oak, with components linked with mortise and tenon joints – both features shared by the original – and also has the only thatched roof permitted in all London since the Great Fire of 1666. The attention to historical detail even extends to the pit area, which remains standing only, albeit with a concrete surface rather than the earthen/straw mix of the 16th/17th century. A second Shakespearean play venue, the Blackfriars Theatre, has been reconstructed and opened as the Sam Wanamaker Playhouse in January 2014.

Trip around the Globe

This famous theatre is unique – but how was it structured?

Roof

In 1599, the Globe had a thatched roof, but it was replaced with tiles after catching fire in 1613. The performance space was open air

Balcony

The Globe's balcony was used for performing as well as a place to position the company's musicians. The balcony was flanked by large wooden columns that supported an overhanging roof

Stage platform

The stage platform extended the stage into the centre of the theatre's pit. At 13.1m wide and 8.2m deep, the stage was raised approximately 1.5m off the floor. It had a trapdoor at the centre for quick entrances and exits

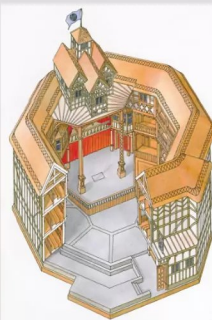
Tiring house

The stage's back wall had three doors on the ground floor and a couple on the first floor as well as a balcony. These doors led to the theatre's backstage area, known as the 'tiring house', where props and costumes were stored and actors prepared to perform

Pit

Surrounding the platform lay the pit, a standing-only area where the poorer visitors could watch. Food and drink were sold here and any rubbish was dropped onto the mud and straw on the ground

The statistics...



Globe Theatre

Opened: 1599

Capacity: 3,000

Stage width: 13.1m

Stage depth: 8.2m

Theatre diameter: 30m

Closed: 1642

Storeys

The Globe had a three-storey seating arrangement used by the middle and upper classes. Basically the higher the seat, the more expensive it was

Foundations

Despite appearing circular in design, with a diameter of just over 30m, the Globe's foundations were actually a 20-sided polygon (icosagon). At the centre of the theatre lay the rectangular stage platform

Entrance (not shown)

There was one main entrance to the theatre, which was directly opposite the stage and led into the pit. Two sets of stairs near the entrance led into the upper seating tiers



Brooklyn Bridge

One of New York's most recognisable landmarks, the Brooklyn Bridge was the first-ever steel-wire suspension bridge

Built between 1870 and 1883, the Brooklyn Bridge links Brooklyn and Manhattan by spanning the East River in New York City. Designed by a German immigrant, John Augustus Roebling, it was his son, Washington Roebling, and daughter-in-law, Emily, who actually oversaw most of the construction after John's unexpected death just months before building commenced.

The bridge consists of two main elements. First, there are the two anchorages that are positioned either side of the river and between them are two towers (also known as piers) which stand at approximately 84 metres high. Consisting of limestone, granite and cement, the towers – designed in a neo-Gothic architectural style – stand on concrete foundations that run 13.4 metres and 23.8 metres deep on the Brooklyn and Manhattan sides, respectively.

Second, the bridge itself is constructed from iron and steel-wire cables, with a layer of tarmac on the main deck. At 26 metres wide and 1,825 metres long, the Brooklyn Bridge was the longest suspension bridge in the world when it was first built, a record that it held for over 20 years. Roebling's design includes many redundancies, such as a diagonal stay system between cables and stiffening trusses, which make the bridge very safe; indeed, even if one of the main support systems were to fail altogether the bridge would sag, rather than completely collapse.

More unusually, the bridge also has its own nuclear fallout shelter built into one anchorage. Having fallen out of use and been forgotten, the shelter was rediscovered in 2006, along with provisions from the Cold War era. Designated a National Historic Landmark in 1964, since the Eighties the bridge has been floodlit at night to highlight its distinct architectural features. Initially intended to carry motor vehicles, trains, street cars, bicycles and pedestrians, since the Fifties, the bridge has only taken cars, cyclists and foot traffic. Over 120,000 vehicles, 4,000 pedestrians and 3,100 cyclists cross it every day.

Suspenders under tension

The two opposing forces – the cables and the bridge deck – in balance produce tension in the suspenders

"More unusually, the bridge also has its own nuclear fallout shelter built into one anchorage"



Tower under compression

The weight of massive masonry towers bearing downwards produces compression

The origins of suspension bridges

In a suspension bridge the deck – the load-bearing portion – is hung below suspension cables on vertical suspenders, which bear the weight. Although bridges of this design first seem to have been invented in 15th-century Tibet, it was really the 19th century which saw their application on a massive scale.

The materials used in the construction of the Brooklyn Bridge were sourced in the US. The granite blocks were quarried in Maine and delivered to New York by boat. The wire rope and steel cable were produced in local factories, while the pigment used in the red paint with which the bridge was originally covered came from the mines at Rawlins, Wyoming.

The design and construction techniques employed in the Brooklyn Bridge have changed little in their essentials over the last century or so. Although at least 81 suspension bridges today are longer than the Brooklyn Bridge, they are all fundamentally the same – except that now the materials tend to be drawn from all over the globe rather than sourced locally.

The Brooklyn Bridge during construction in the late-19th century



Cultural impact

Since its completion, the Brooklyn Bridge has inspired many an artist and poet. The modernist American poet Hart Crane, for example, famously published the ode *To Brooklyn Bridge* in 1930. Regarded as a wonder of its age, people flocked to see the structure's opening with a spectacular fireworks display and regatta in 1883 – a celebration which was repeated on its 100th anniversary.

Many people have jumped off the bridge as publicity stunts or suicide attempts, while others have got married on it. In 1919 the Caproni heavy bomber, which was then the world's largest aeroplane, was flown under the deck, while in 2003 it was the intended target of an Al-Qaeda terrorist plot.

The Brooklyn Bridge has also frequently appeared in Hollywood movies, such as *I Am Legend*, *The Dark Knight Rises*, *Godzilla*, and more recently *The Amazing Spider-Man 2*.

Live load

The weight of the traffic that crosses the bridge, as well as normal environmental factors such as wind and rain

Cable under tension

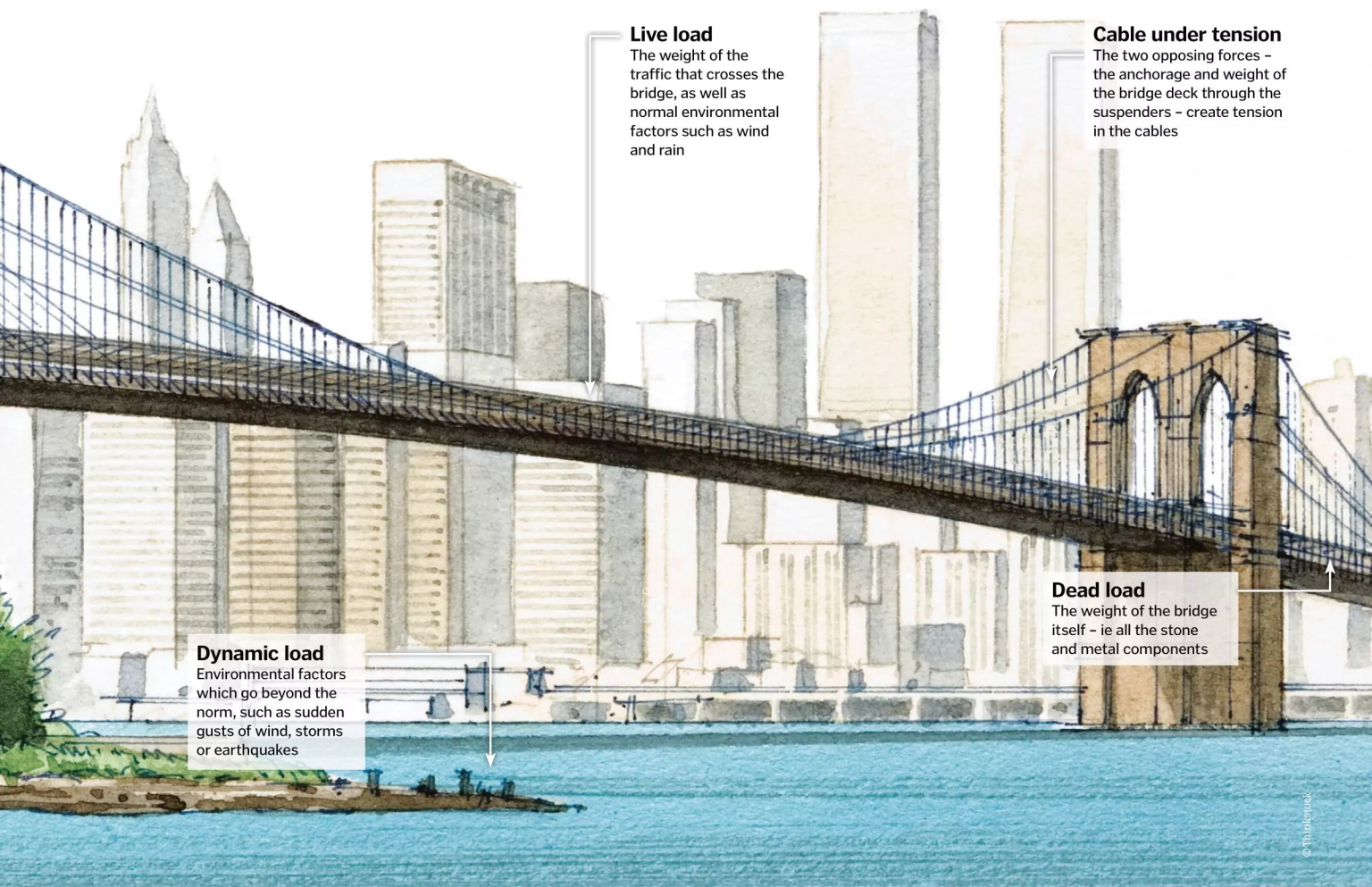
The two opposing forces – the anchorage and weight of the bridge deck through the suspenders – create tension in the cables

Dead load

The weight of the bridge itself – ie all the stone and metal components

Dynamic load

Environmental factors which go beyond the norm, such as sudden gusts of wind, storms or earthquakes





What went wrong at Chernobyl?

Learn how a runaway reaction led to a nuclear disaster...

On 25 April 1986, engineers at the nuclear plant at Chernobyl began a test that would lead to the worst nuclear disaster in history. The power plant, located around 130 kilometres north of Kiev, Ukraine, was completed in 1983. Three years later, engineers ran an experiment to see how long the turbines could continue producing energy in the event of a power cut.

The first fatal error made by the technicians that day was to turn off the crucial safety systems in the facility. They would have affected the experiment, which involved running the plant at low power, but this action prevented workers realising the dire situation they were soon to put themselves in.

The process of creating nuclear fission is regulated by control rods, which, when inserted into the reactor core, absorb neutrons and slow production. The idea was to lower lots of these rods to reduce the power output and see what happened. Unfortunately, too many were lowered and the output dropped at too high a rate. Rods were then raised again to increase output, returning to about 12 per cent.

However, due to the rods being raised too far and too quickly, a dangerous power surge occurred and the reactor overheated; the water cooling system, unable to cope with the sudden demand, turned to steam.

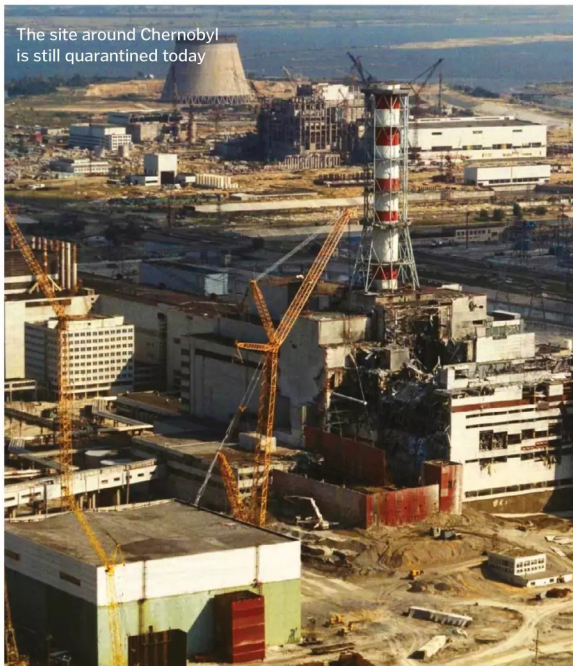
The emergency button was pressed and the rods began to lower but this led to even more rapid reactions in the core.

In the early hours of 26 April, the reactor's roof was blown off and radioactive material began to escape into the atmosphere.

The fire took nine days to extinguish and the radioactive material had far-reaching health and political consequences.



The site around Chernobyl is still quarantined today



Nuclear fallout

The explosion and meltdown was shocking enough, but worse was still to come in the form of radiation spread and health issues for much of Europe.

31 people died immediately after the event with 28 of those deaths a direct result of radiation poisoning inside and around the power plant site.

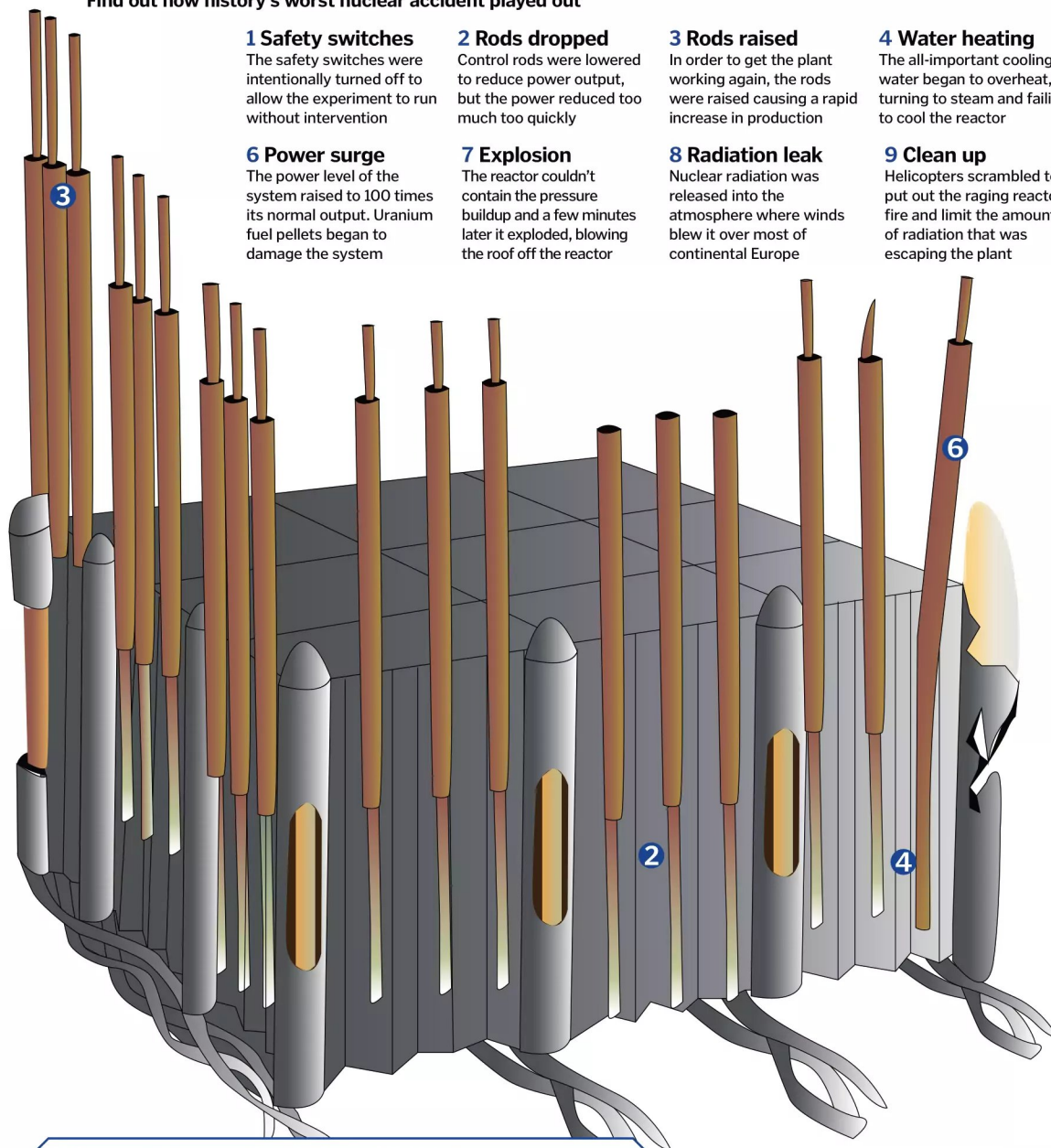
The worst of the fallout centred around Chernobyl, but increased levels of radiation were detected in areas as far away as the UK, Portugal and Sweden.

Thyroid cancer, caused by the inhalation of contaminated air, has increased tenfold in adolescents in Belarus since 1986 with cases in adults also rising. Cases in children up to the age of 14 also increased, but that number has since reduced due to many of that age group being born after the event.

The impact of the contaminated air has also affected animals, crops and water supplies and the effects are still widely felt to this day. Radiation levels around Chernobyl will remain far higher than average for many millennia.

Countdown to disaster

Find out how history's worst nuclear accident played out



1 Safety switches

The safety switches were intentionally turned off to allow the experiment to run without intervention

2 Rods dropped

Control rods were lowered to reduce power output, but the power reduced too much too quickly

3 Rods raised

In order to get the plant working again, the rods were raised causing a rapid increase in production

4 Water heating

The all-important cooling water began to overheat, turning to steam and failing to cool the reactor

5 Emergency

Pressing the emergency button lowered the rods again, but they displaced the remaining water

6 Power surge

The power level of the system raised to 100 times its normal output. Uranium fuel pellets began to damage the system

7 Explosion

The reactor couldn't contain the pressure buildup and a few minutes later it exploded, blowing the roof off the reactor

8 Radiation leak

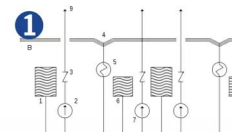
Nuclear radiation was released into the atmosphere where winds blew it over most of continental Europe

9 Clean up

Helicopters scrambled to put out the raging reactor fire and limit the amount of radiation that was escaping the plant

10 Sarcophagus

A concrete shell was hastily constructed and placed over the nuclear plant to limit the release of radiation from Chernobyl



How it toppled the USSR

The leader of the Soviet Union at the time of the Chernobyl disaster, Mikhail Gorbachev, has claimed that the incident was a key factor in the demise of the USSR.

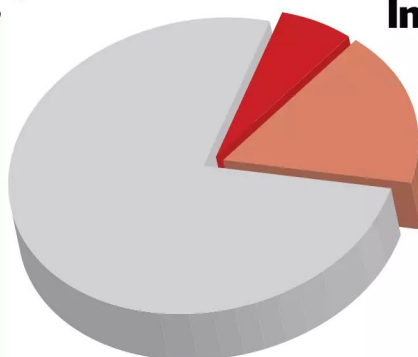
The government's response to the disaster was to try and cover it up as much as possible, with barely any official announcement of it and no warning to residents in the surrounding area as to the dangers of radioactive poisoning. It took a radioactive cloud that passed over Sweden to bring the event to the world's attention.

Furious at the lack of information and protection they had received, especially as Gorbachev had promised a new era of political clarity and honesty, citizens rallied against the political system.

The general public lost faith in the government and the government in turn lost control of the general public. Five years later, the Soviet Union was dissolved, with Gorbachev quoted as saying, "The nuclear meltdown at Chernobyl [...] was perhaps the real cause of the collapse of the Soviet Union."

Impact of the meltdown

How many were directly affected by the disaster?





WEAPONS & WAR

060 **History's deadliest warriors**

The lethal fighters that struck fear through the ages

066 **Spies through history**

Discover the secrets of espionage through the ages

072 **The Siege of Tyre**

Experience the epic conquest of Alexander the Great



074 **Brutal battering rams**

How were these powerful siege engines built and used?

075 **Vickers-Maxim gun**

Stare down the barrel of this deadly British weapon

076 **Meet the musketeers**

The origins of this popular military unit

078 **Inside the Manhattan Project**

Discover the secrets of the most powerful weapon the world had ever seen

082 **Sikorsky MH-60 Black Hawk**

How did this incredible war machine revolutionise aerial warfare?

074 **Brutal battering rams**

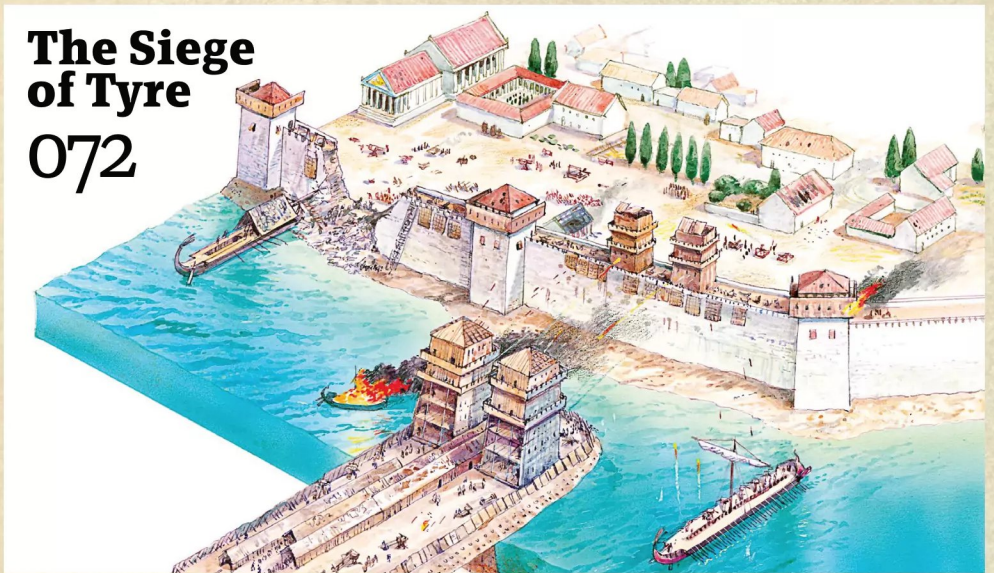


076 **Meet the musketeers**



The Siege of Tyre

072



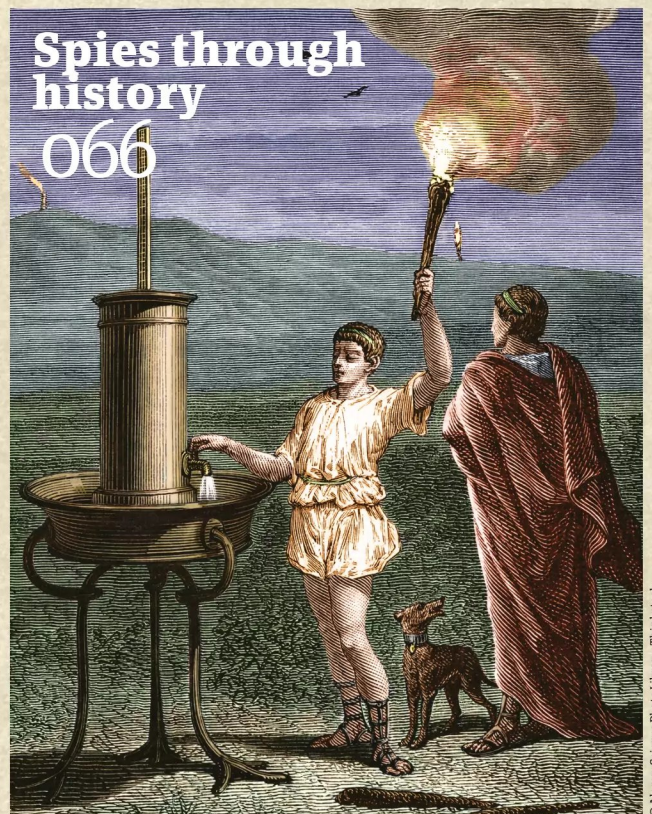
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MH-60 Black Hawk



Spies through history

066



060

History's deadliest warriors

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HISTORY'S DEADLIEST WARRIORS

Lethal fighters who could strike fear into the hearts of even the most battle-hardened enemy

Throughout history, many soldiers from across the world have been contenders for the title of the deadliest warrior, but who really was the most formidable? It takes more than just sheer strength or bloodlust to be considered a legendary fighter.

Most important of all is weaponry; even the toughest soldier can be defeated in a one-on-one dual by a rival with superior firepower. As the old adage goes, don't bring a knife to a gunfight, and the best fighters are always equipped for the job, whether it's a huge pitched battle or a covert operation. A popular theory as to why Custer's men were trounced at Little Bighorn was the fact that the Sioux warriors may have wielded superior rifles to the US Army.

Just as essential as having the right tools is using the right tactics. With a well-planned and efficiently executed strategy, soldiers can outmanoeuvre and outthink a numerically

superior force or a physically stronger enemy. In a hypothetical battle between a samurai and ninja of Japan, for example, the use of underhand tactics could easily give the ninja an upper hand against a samurai bound to his moral code and obligated to fight with honour.

Finally, a deadly warrior must have the right attitude and appetite to emerge victorious. Whether it's to protect their homeland or simply earn a wage as a mercenary, a fighter with a purpose is much more dangerous. During the Crusades, Christians and Muslims fought to uphold their religious values and would take to the battlefield again and again in the name of their faith.

Ranging from ancient times to the modern era, read on to learn about some of the deadliest warriors in history. Any soldier would want these legendary fighters standing by their side on the eve of battle.

CIRCA 476-206 BCE

Qin soldier

The military that fought ruthlessly to unify China

The Qin Dynasty was a period of great progress for China. The new emperor Qin Shi Huang made a series of sweeping changes that unified the country and modernised its military. In came China's first professional conscripted army, staffed by formidable soldiers and led by skilled generals. Qin soldiers used some of the most advanced weapons during the era, from sharp iron swords to powerful crossbows.

Their role on the battlefield as shock infantry was supplemented by more heavily armed foot soldiers, as well as flanking cavalry and chariots. The warriors that battled on horseback were held in the saddle by a new invention, the stirrup, giving them greater balance than their adversaries. Some of their enemies were worthy foes, in particular, nomadic tribes from the north with mounted archers. But fuelled by a desire for conquest and loyalty to their emperor, the Qin often held their own in battle.

Notable battle... QIN'S WARS OF UNIFICATION 236-221 BCE

Hairstyle

A Qin soldier's hairstyle denoted rank as well as his unit. Braids in a leather cap were a popular choice that didn't obstruct the fighter in battle

Bronze sword

Qin swords were originally made from bronze, but were later replaced with tough iron

Ribbons

The number of ribbons fastened to the chest plate was another way of indicating the soldier's rank

Armour

Light robes, padded trousers and iron-riveted armour allowed the well-protected warriors to remain nimble

Pilum

A type of heavy javelin, the pilum had a strong tip and was weighted in such a way that it could pierce enemy armour

Helmet

Called a galea, the Roman helmet absorbed blows to the head and protected the side of the face

Gladius

Unsheathed after the pilum had been thrown, the gladius would be used in tight melees to thrust and stab the enemy

WEAPONS OF CHOICE

PILUM, GLADIUS, PUGIO

Chain mail

Even though Romans are often associated with lorica segmentata armour, legionaries also wore chain mail

CIRCA 400 BCE-476 CE

Roman legionary

One of the ancient world's finest armies comprised dedicated, hardened soldiers

The Roman legions were the finest fighting force on Earth for hundreds of years. Manned by well-drilled legionaries, they conquered most of Europe as well as parts of Africa and Asia Minor.

At the height of Roman power, the primary tactic was to throw a spear called a pilum into the enemy masses. It would either impale them or stick in their shields, rendering them unusable. After this, the legionaries drew a short sword, called a gladius, and charged at their foes. Legionaries first wore chain mail but later changed to lorica segmentata. These overlapping metal strips were just as protective but allowed the soldiers to be more agile in combat.

Despite being ferocious warriors in their own right, the prowess of the legionary was complemented by intelligent strategies. Formations like the testudo (tortoise) and siege weapons like the ballista could often be the difference on the battlefield and helped legions overwhelm opposing forces larger than their own. The Roman legions were also often better prepared than their enemy. Legionaries carried saws, rope, pickaxes, cooking pots and rations to set up camps deep into enemy territory.

In the later days of the empire, Roman tactics and armour changed as auxiliary soldiers sourced from around the empire began to fill the ranks. Being a legionary was a well-respected career in the empire, and victorious generals were treated to celebratory processions on their return to Rome.

Notable battle...

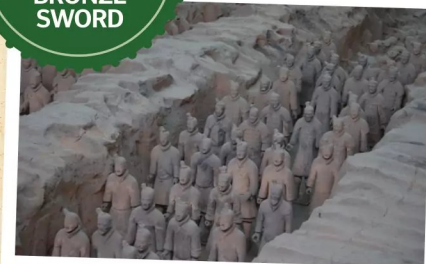
BATTLE OF PYDNA, 168 BCE

Sandals

The Roman legionary marched in thick, heavy sandals that were stuffed with wool or fur in cold weather

Scutum

The iconic rectangular wooden shield protected the body and was glued carefully so it could interlink in the testudo formation



The Terracotta Army is made up of ceramic versions of Qin soldiers. The statues were buried with the emperor in his tomb to accompany him in the afterlife

Roman training

Legionaries were trained to be superior to their enemies. To become part of the legion, the soldiers would be judged on their height, their eyesight and their physical fitness. Recruits were taken on from the age of 18 and would be expected to march up to 30 kilometres a day. A huge emphasis was placed on training, from battlefield formations to swordplay. In specialised training schools, legionaries fought with wooden swords and could lose rations if they did not perform well.





8TH-11TH CENTURY

Viking raider

These brutal warriors devastated coastal towns right across Europe

Anglo-Saxon Britain was assaulted by a series of raids by Norsemen from Scandinavia. Pitching their longboats up on the shore, Vikings pillaged the local area before returning to their ships with valuable plunder. As time wore on, the attacks became more and more frequent and an area known as the Danelaw was established, encompassing northern and eastern England. Wealthy Vikings used double-edged swords, but the majority of fighters carried axes or spears into battle.

The Vikings didn't have standardised tactics, giving them greater variety on the battlefield. Warriors called berserkers went into battle brandishing huge two-handed axes that they used to hew down anyone who got in their way.

The Vikings had a rich appetite for battle as well as an upbringing based on the necessity of war. The longboat helped initiate rapid attacks that would strike an enemy before its forces could retaliate. These tactics helped them conquer not just parts of the British Isles but also territories in Spain, France and Russia. The emperor of the Byzantine city of Constantinople even had his own Norse bodyguards, the Varangian guard, who were some of the toughest mercenaries of the era.

Notable battle...

ATTACK ON LINDISFARNE 793 CE

Ringed mail

Chain mail coats were worn by some chieftains into battle

Weapon

The most popular Viking weapons were axes, swords and spears

Iron dome

Viking helmets did not have horns but they did have visors that helped protect the wearer's face



Keeping warm

In cold temperatures on land and at sea, a thick under-tunic was worn below the armour

Round shield

Circular shields were made of wood and iron and attached to the side of a longboat when travelling

Bascinet

The iconic fully enclosed Crusader helmet protected the face and the neck

From mail to plate

Early Crusader knights wore chain mail, but this later changed to more durable and protective plate armour

Broadsword

The Crusaders' swords weren't always sharp - some were more effective as clubs rather than cutting instruments



"The Pope promised that anyone who fought would be forgiven their sins"

Kite shield

The kite or tear shaped shield could be strapped on a Crusader's back to carry on long journeys

11TH-13TH CENTURY

Crusader knight

Clad in protective armour, these western knights fought in holy wars approved by the Pope

Between 1096 and 1272 there were a total of nine crusades to the Holy Land. The foot soldiers of these Christian armies fought to reclaim Muslim-controlled cities like Jerusalem, which they believed to be rightfully theirs. Pope Urban II initiated the First Crusade, promising that anyone who fought would be forgiven for their sins.

The Crusaders' iconic look was completed with a red cross emblazoned on a white surcoat. This was worn to identify each knight as a Christian as well as protecting the metal armour from the hot Sun.

The knights fought both on horseback and on foot as the ownership of the Holy Land changed hands

between the Crusaders and the Saracens frequently. Many bloody battles were fought as huge losses mounted on both sides. Both forces still continued fighting undeterred though, fuelled by religious passion and an unwavering belief that they were dying in their god's name.

Notable battles...

SIEGES OF ANTIOCH (1097-1098), SIDON (1110) AND ACRE (1189-1191)



1325-1521

Aztec eagle warrior

The warriors of the Sun who formed an elite fighting force

Prior to the arrival of the Spanish conquistadors, the Aztec Empire dominated vast areas of modern-day Mexico. One of the infantry types that helped maintain control were the eagle warriors. Along with jaguar warriors, they formed an elite unit of Aztec society that was renowned for its military prowess.

To be part of the society, an Aztec had to prove their worth on the battlefield by capturing a set number of enemy soldiers to be used in sacrificial rituals. The aim of returning foes for sacrifice meant that most of the eagle warrior's weapons were designed to wound, not kill.

The Aztec society did not have the technology to smelt metal so they used the world around them to arm themselves. Rocks were collected as ammunition for slings, turkey feathers were used to fletch arrows and tunics were soaked in salt so they would crystallise and harden. Eagle warriors also carried unique weapons like the atlatl, a spear and dart throwing device, and the macuahuitl, a blunt wooden paddle with sharp glass blades protruding from it.

Notable battles...

**FALL OF TENOCHTITLÁN 1521,
BATTLE OF OTUMBA 1520**

Warriors of the Sun

Warriors wore a feathered headdress and wooden headgear that symbolised a bird's open beak.

Protection

The warriors wore a quilted cotton tunic and carried a brightly coloured, feathered, round leather shield called a chimalli.

Macuahuitl

A favourite weapon was the macuahuitl, a wooden paddle with glass made from volcanic rock embedded in it.

WEAPONS
OF CHOICE

MACUAHUITL,
ATLATL

Other weapons

As well as spears, eagle warriors carried slings and bows tipped with either rock, bone or obsidian.

Captive soldiers were often gruesomely sacrificed to the gods.



Hidden identity

The secretive ninjas hid their identity whenever possible, so few ninjas from history are known by name.

Weaponry

Ninjas were experts at using poison, and would add it to an enemy's food or infuse their blades with it.

A life in the shadows

Even though they carried swords and other weapons, ninjas only fought when absolutely necessary, preferring a silent kill or stealthily gathering secrets.

WEAPONS
OF CHOICE

SHURIKEN,
MANRIKI-
GUSARI,
FUKIYA

Sneaky operations

Ninjas were especially useful in sieges, infiltrating castles and distracting the surprised defenders.

Dressed in black

The archetypal ninja is dressed head to toe in black, but they would only wear this attire for when it was needed, such as covert operations at night.

Martial arts training

Ninjas were trained in martial arts like jujitsu, so they were a dangerous foe even when unarmed.



10TH-17TH CENTURY

Ninja

With stealth as a priority, ninjas struck silently from the shadows.

Among the most famous assassins in history, the ninja were dangerous adversaries in feudal Japan. Also known as shinobi, in folklore the ninja were first formed to fight back against oppression from the ruling class by a rogue samurai who went against the bushido code.

They practised ninjutsu, the art of stealth, which taught special ninja combat skills and how to remain hidden. Ninja were the opposite of the samurai, and rather than having codes based on honour like Bushido, they would happily covertly kill their enemies, an act considered immoral by the samurai. But this didn't mean that the two were enemies, instead, the ninja were often employed to aid the samurai.

Contrary to popular depictions, ninjas didn't just wear black; they dressed to blend in, so they would just as likely be clad in civilian clothing to avoid detection. In combat, ninjas would use standard Japanese weapons of the era, but also wielded their own special equipment. The shuko was a small device used for traction when scaling walls and a tessen was an inconspicuous metal fan that could be used as a weapon.

Ninja combat may not have been just reserved for men, either; tales of female ninjas, or kunoichi, described their dressing as servants or dancers to secretly infiltrate forts and compounds to get closer to a target.

Notable battles...

**NANBOKUCHO WARS 1331-1392,
ONIN WAR 1467-1477**

Ninja tool kit

An array of weapons and accessories helped ensure ninjas always had a trick up their sleeves.



Kakute

Similar to a knuckleduster, kakute were small, spiked iron rings worn around the fingers. They were an asset in hand-to-hand combat.



Shuriken

These throwing stars could quickly and secretly eliminate targets from distance. They were small enough to be hidden in clothing.



Fukiya

Blowpipes launched poison darts at enemies or sent secret messages to allies. They could also be used as breathing straws.



14TH-19TH CENTURY

Ottoman janissary

The elite infantry of the Ottoman Empire

For centuries the Ottoman Empire's mighty army was led by janissaries. The first force was formed around 1380 by Christian prisoners captured after successful Ottoman campaigns in Europe. Aged between six and 14, they were taken from their homeland and bred for battle. After being drafted into the army, they became the property of the sultan and acted as his personal bodyguards.

The janissaries were forced to observe strict rules and were trained to a high standard as disciplined and skilful warriors. As the sultan's most trusted guards, the companies resided in barracks and were constantly drilled for a life of war. The janissary commander was called the agha and ranked above other commanders in the Ottoman military.

Janissaries used swords and rifles as they moved quickly to overwhelm fortresses or to outflank cavalry. On the battlefield, janissaries were recognisable due to their distinctive headgear. They also fought at sea, using their rifles to fire at mariners on enemy ships. They gained a reputation as some of the best marksmen in the world, deploying devastating walls of fire.

In peacetime they also served in Ottoman cities as policemen. At their peak in the early 19th century, there were over 100,000 janissaries and the Ottoman Empire represented one of the finest fighting forces in the world.

Notable battles...

SIEGE OF CONSTANTINOPLE 1453

BATTLE OF MOHÁCS 1526

Robe

A felt robe was worn in place of armour. Lightweight and flexible, it allowed janissaries to move swiftly and engage in naval operations



Headgear

A janissary's headgear was unique and designed to strike fear into enemies, who could recognise the formidable force from a distance

Axe

When fighting at close quarters, a janissary would swing their axe, hacking away at anyone that crossed their path

Breeches

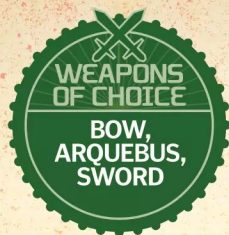
Long robes were stuffed into breeches so they were out of the way both during marching and in the midst of battle

Primary weapon

Starting off as archers, janissaries soon modernised and wielded arquebuses, becoming some of the most accurate marksmen in the world

Secondary weapon

With its curved blade the yatagan sword was useful on the battlefield as well as an enduring symbol of the janissary



War paint

A Sioux warrior's face and body were covered in war paint, and bird feathers were worn in the warrior's hair

Shield

The small shield was made of animal skin or leather and could deflect enemy arrows



Bow and arrow

The Sioux bow shot iron arrows over a short range, and some were backed with animal tendons to provide extra power

Tomahawk

Before rifles were introduced by settlers, axes were used as both melee and projectile weapons



PRE-EUROPEAN COLONISATION-1890

Sioux warrior

Native American warriors who preferred to count coups rather than draw blood

Unlike many of the other warriors on this list, the Sioux seldom fought in large numbers. They preferred to attack in small raiding parties that focused on stealing horses or avenging a fallen comrade rather than occupying territory.

The Sioux, like other Native American tribes, did not believe in the ownership of land, but they did compete with rivals like the Crow for hunting and living space in the summer months. Both Sitting Bull and Crazy Horse were Sioux warriors, and it was any young man's ambition to prove their status

within a tribe. In Sioux warrior societies it wasn't considered heroic to die, and instead the ultimate show of courage was to touch an enemy with a coup stick.

Enemies that were killed were scalped. This, the Sioux believed, prevented enemies from revisiting warriors in the afterlife, and scalps would be hung as spoils of war outside tipis and on spears and shields.

Notable battle... BATTLE OF LITTLE BIGHORN 1876

PRE-EUROPEAN COLONISATION-19TH CENTURY

Zulu warrior

The men who defied the European imperialists

Zulus were divided up into regiments of hundreds or thousands of warriors called an ibutho. Younger unmarried men comprised the main fighting force, and to maximise their time in service, chiefs often didn't let their troops marry until their mid-30s. When a Zulu was married, they could choose to leave the ibutho and from then on were only required to fight in times of war.

Shields were only issued in wartime; Zulus were not allowed to own one in peacetime to help quell potential civil war. Younger regiments tended to have darker shields while more experienced contingents defended themselves with lighter coloured versions. The shields themselves were used to knock enemies off balance before stabbing them with short spears. As well as being traditional, it helped Zulu leaders identify different units on the battlefield. There wasn't a standing army and Zulu warriors returned to their homes between conflicts.

The army didn't have any sort of supply system and lived off the land. This made operations short but often decisive. The Zulus knew the lay of their land better than anyone, which made ambush attacks highly effective. Their prowess in battle enabled the Zulus to conquer rival tribes and made them more than a match for the invading Europeans.

Notable battles...

**BATTLE OF ISANDLWANA 1879,
BATTLE OF RORKE'S DRIFT 1879**

Assegai

Equipped with a sharp, pointed blade, this spear was used to stab enemies from behind a large shield

Modern firearms

As well as spears, Zulu warriors also wielded rifles that had been imported into Africa by settlers or taken from defeated foes

Stamina

With no supply train or heavy armour, Zulu forces could cover over 30 kilometres in a day

Headdress

Zulu regiments wore distinguishing headdresses so their commanders could orchestrate battles from a distance

Isihlangu

A Zulu war shield was made from cowhide and when beaten with a spear, made a loud intimidating noise

Cowhide

The cowhide used to make the shields was made extra durable by drying it in the Sun, burying it under manure and then hitting it with rocks

WEAPONS OF CHOICE
ASSEGAI, RIFLE

Horns of the buffalo formation

When the Zulus delivered a crushing defeat to the British at the Battle of Isandlwana in 1879, they had their tactics to thank. The formation was pioneered by Zulu king Shaka and involved a strong central core of warriors flanked by horns – two units of light troops. As the enemy moved to engage the strongest Zulu units in the centre, they would be flanked and encircled. This strategy was devastatingly effective against local tribes but was less successful against the British, especially at Rorke's Drift, where concentrated rifle fire prevented the Zulus from getting in close. However, against the scattered British forces at Isandlwana, it led to an emphatic victory.

ENEMY

ZULU FLANKING FORCE - HORNS

ZULU MAIN FORCE - HEAD

ZULU RESERVE FORCES

The two flanking horns would pressure the enemy toward the main body of the Zulu force

King Shaka introduced new military tactics

1815-PRESENT

Gurkha

Loyal and fearless, they were a vital asset to Britain in WWI

During World War I, Gurkhas were some of the finest soldiers on the side of the Allied powers. They travelled from their native Nepal to many theatres of the war, including the treacherous cliffs of Gallipoli and the blood-soaked fields of the Western Front. Time and again, the brave Gurkhas led assaults on key positions.

Gurkhas were first enlisted by the British in 1815 and around 3,500 still serve in the British Army. Almost 2,000 were awarded gallantry awards during the Great War and several have received the Victoria Cross. Their motto is 'better to die than be a coward'.

Notable battles...

BATTLE OF LOOS 1915, GALLIPOLI CAMPAIGN 1915-1916

Battlefield courage

Gurkha regiments universally wore this headgear during WWI for traditional reasons

Kukri

A distinctive curved knife made of tempered steel, the kukri was a lethal weapon in practiced hands

WEAPONS OF CHOICE
KUKRI

Weapon and tool

The kukri can also be used to chop food and wood. An old legend stated that it had to draw blood every time it was drawn

Over 200,000 Gurkhas served as allies of the British in the two World Wars



SPIES THROUGH HISTORY

The secrets of espionage through the ages

The principle of gathering confidential information, from secret documents to military tactics, has proved invaluable for rulers, empires and governments throughout history. Covertly collecting information about enemies, and even allies, provided nations with the opportunity for military, political or economic gain.

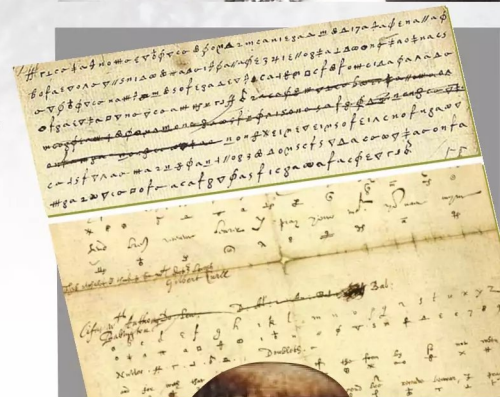
Espionage is the gathering of secret information, and the methods used changed dramatically as technology developed. In ancient Rome, letters could be intercepted en route to their intended recipient. In an attempt to prevent this, Julius Caesar invented one of the earliest-known ciphers – a code used to disguise messages – to stop enemy spies reading his secret military communications.

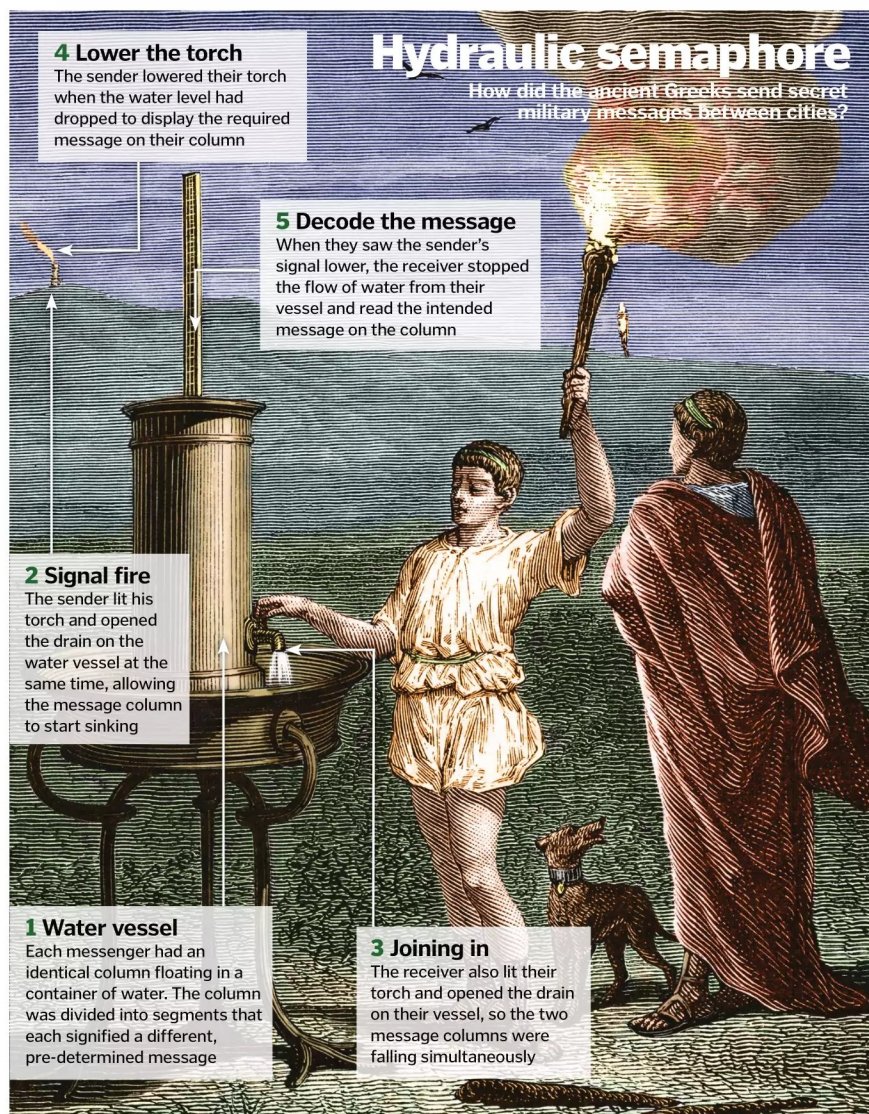
In the 20th century, espionage was particularly important during the two World

Wars, as nations established huge intelligence networks in an effort to stay one step ahead of the enemy. Some estimate that deciphering the Nazi's 'uncrackable' Enigma machines (used to encode messages) helped shorten World War Two by several years, saving countless lives.

During the Cold War, with the threat of nuclear war between the US and Soviet Union looming, strategic intelligence was vital and influenced tactics on both sides. Spies disguised gadgets as everyday objects to help gather information, from coat button cameras to microphones hidden in shoe heels.

Counterintelligence operations continue to be incredibly important to this day. Security services across the world work to protect their citizens against threats to national interests, conducting counter-terrorism operations and tackling cyber crime.





"Eavesdropping, intercepting messages and scouting enemy movements were the key methods used to gather intelligence"

Ancient espionage

How intelligence was gathered by ancient civilisations

In the first cities of ancient Mesopotamia and ancient Egypt, spying was an effective way for kings and pharaohs to monitor the population, as well as to discover enemy weaknesses. The ancient Egyptians used court spies to root out disloyal subjects, and they were also among the first to develop poisons for sabotage or assassinations.

With no spy gadgets at their disposal, eavesdropping on conversations, intercepting communications and scouting enemy movements were the key methods used to gather useful intelligence. Resourceful techniques were developed to ensure written messages remained secret, including codes and trick inks.

The ancient Greeks excelled at espionage and subterfuge. The legendary tale of the Trojan horse became a symbol of their cunning and deceptive military tactics. They developed efficient methods of communicating important messages between cities, including a fire signal system known as hydraulic semaphore.

Another tactic used by the Greeks to prevent communications being intercepted was carving important messages into wood and then covering it in wax. The wooden board would then be sent to an ally who would melt the wax to read the message. A more gruesome method was writing on the outside of an inflated animal bladder, before deflating it and packing it into a flask. The document could then be transported anywhere unnoticed until it was opened, inflated and read.

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Julius Caesar's speculatores

The Roman Republic was a fragmented, unruly place and keeping hold of power was never easy. Many rulers hired bodyguards for protection, but Julius Caesar saw the value of secret surveillance and used spies called 'speculatores' to gather intelligence of potential revolts. This reconnaissance network helped Caesar keep abreast of goings on both domestically and internationally. Some sources suggest that Caesar was aware of the Roman Senate-led plot to assassinate him.



Not even Caesar's speculatores could prevent his assassination

The Mongol spy network

United under leader Genghis Khan, the Mongols were one of the most feared military forces of the 12th and 13th centuries as they rampaged across Asia. However, this mighty army would not have been as successful had it not been for an extensive intelligence network. Genghis Khan gathered information from trade merchants, who had an in-depth knowledge of the areas he wished to conquer. This intelligence allowed the Mongols to pinpoint weaknesses in enemy territories.



Spies' information gave the Mongols an advantage when conquering new lands

Elizabethan espionage

The final Tudor monarch created a secret service network that helped keep her on the throne

Agents in Elizabeth's spy network gathered information about the Spanish Armada's preparations

As a Protestant queen with no heirs, Elizabeth I's reign was threatened by those who would have preferred the Catholic Mary Queen of Scots. With the threat of assassination, the Queen set up a network of spies to protect her against dissidents and uncover foreign plots. Head of Elizabeth's secret service was Sir Francis Walsingham, a Protestant lawyer. Those hired as spies were among the greatest minds in the land; scholars, scientists and linguists were all tasked with protecting the vulnerable monarchy.

Technological advancements also aided the intelligence network. Invisible ink made from milk or lemon juice was first utilised in this period, allowing secret messages to be revealed by warming the paper over a candle. Cryptography became more advanced, and the spy network needed to be able to both write and decipher different codes.

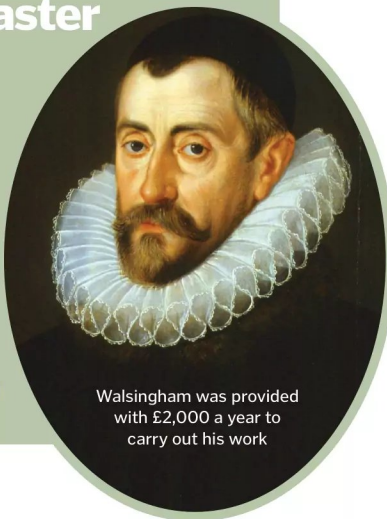
A series of plots to overthrow or assassinate the Queen were uncovered during her reign. The intelligence gathered by Elizabeth's secret service most likely saved her life on more than one occasion. For example, after her imprisonment, Mary Queen of Scots maintained contact with the outside world by sending coded messages to her allies hidden in barrels of beer. Little did she know that the barrels were being smuggled by a double agent acting on behalf of Walsingham, who deciphered her messages and proved that Mary was involved in a plot to kill Elizabeth. Those involved, Mary included, were quickly caught, tried and executed for treason.



Elizabeth's spymaster

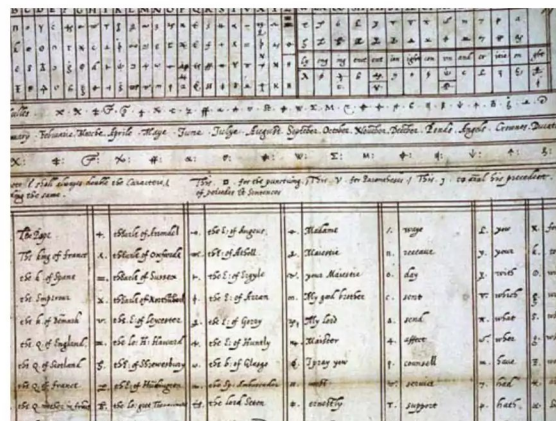
At the head of the Elizabethan spy network was the secretary of state, Sir Francis Walsingham. With threats coming from Catholic Spain, devout Protestant Walsingham built up a network of spies all over Europe – including prison informants and double agents – with the aim of gathering intelligence about the activities of Catholics, as well as political and economic information.

To ensure his agents were as effective as possible, Walsingham established a spy school to train new recruits. His network proved invaluable to national security after foiling several plots against the Queen, as well as providing intelligence about the Spanish Armada leading up to the attempted invasion in 1588.



Walsingham was provided with £2,000 a year to carry out his work

Mary sent secret messages to her allies using these cipher symbols, but Walsingham's spies decoded them



World War spies

How inventive spying strategies were used to try and win both global conflicts

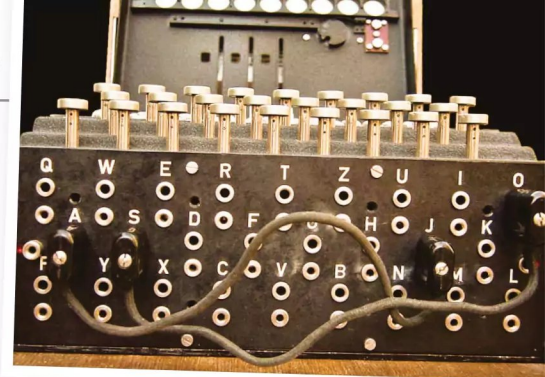
World War One may be remembered primarily for trench warfare, but behind the lines, spies were performing a vital role. One of the most successful spy networks during the war was codenamed 'La Dame Blanche'. With over 1,000 members, the organisation worked for the British, conducting valuable reconnaissance missions in German-occupied Belgium, spying on trains, roads and airfields.

The development of aircraft in the early 20th century meant that aerial reconnaissance was also a large part of the war. Both German and French planes took photos from above to examine troop movements. German intelligence greatly helped its divisions push forward on the Eastern Front. By acquiring secret documents and intercepting radio messages, they knew what moves the Russians would make.

When World War Two began, espionage was still an instrumental part of warfare.

Germany's military intelligence organisation, the Abwehr, was particularly effective during the occupation of the Netherlands. The group captured 52 Allied agents and 350 resistance fighters, some as soon as they parachuted in. Still under the illusion that they were supplying their Dutch allies, the British unwittingly provided the Germans with 570 boxes of weapons and ammunition.

Most famously, the Nazi's Enigma machines were used to ensure their army's messages remained secure. To send a signal, an operator typed in their message and then scrambled it using a series of rotors, which would reproduce the message as a jumble of different letters. The receiver would need to know the exact settings used by the sender in order to decode the

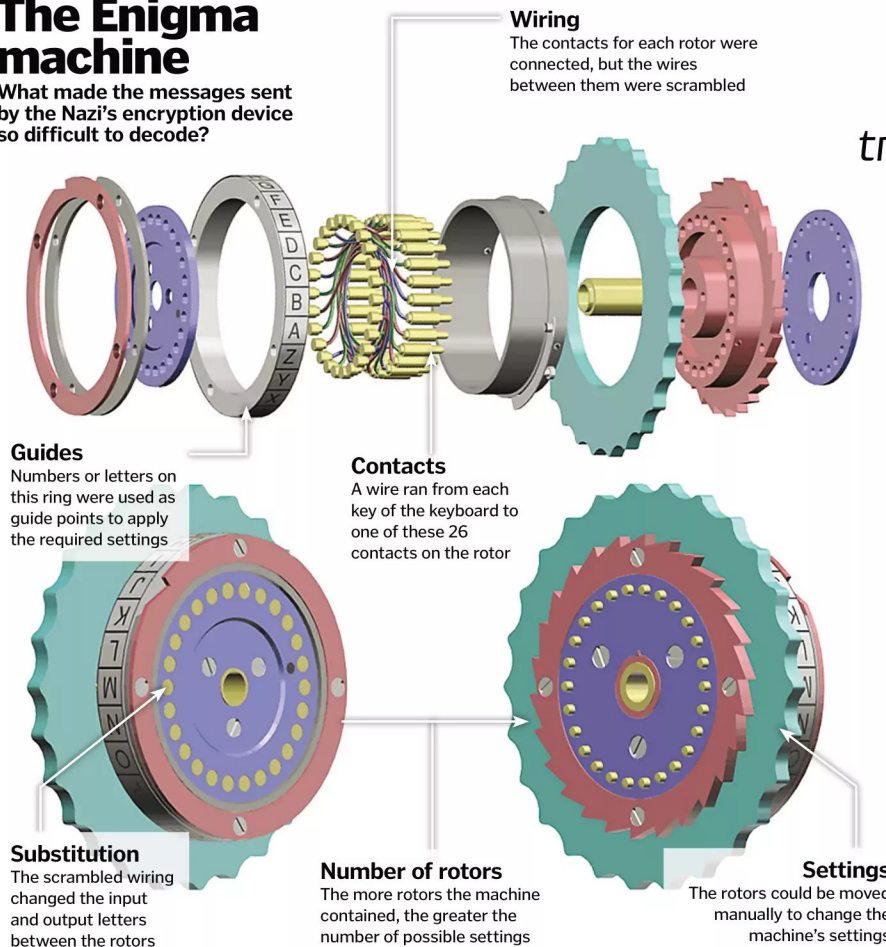


On the front face of the Enigma machine was an electronic plugboard that could be used to swap pairs of letters, for an extra level of encryption

original message on their own machine. The settings were frequently changed, and a typical army-issue Enigma machine could have over 150 million trillion different settings, so cracking the code was considered impossible. The British eventually managed to decipher Enigma after teams of mathematicians and code-breakers at Bletchley Park developed computers known as bombes that could work out the machine's settings based on an intercepted coded message. Some historians estimate that the intelligence the Allies gathered by breaking the Enigma code helped shorten the war by two years.

The Enigma machine

What made the messages sent by the Nazi's encryption device so difficult to decode?



"A typical army-issue Enigma machine could have over 150 million trillion different settings"

World War spies

The shady double agents that provided intelligence to the opposition



Howard Burnham

Burnham was an intelligence officer for the French government in World War One and often hid his spying equipment in his wooden leg.



Mata Hari

A Dutch dancer, Hari spied for the Germans before being caught by the French and sent to the firing squad in 1917.



Virginia Hall

Hall was a US spy during World War Two who provided support, information and training for resistance fighters and the Allies in occupied France.



Takeo Yoshikawa

Living in Hawaii during World War Two, Japanese spy Yoshikawa provided intelligence to his country ahead of the surprise attack on Pearl Harbor.

Cold War espionage

After the Second World War, a new era of spying emerged during a bitter rivalry

A decades-long power struggle between the US and the USSR began after the collapse of the Third Reich. The nations held opposing ideologies – capitalism versus communism – and had a mutual distrust of one another's intentions. Tensions rose as both powers entered into an arms race and the threat of a devastating nuclear war grew. Espionage was one of the primary methods used to try and break the deadlock. Each of the two superpowers was determined to gain the upper hand, so spies were sent all over the world to gather intelligence about the enemy.

One of the most infamous spy networks behind the Iron Curtain was the Ministry for State Security, commonly known as the Stasi. Operating in East Berlin, the organisation used brutal methods to monitor the activities of the East German capital's citizens. Stasi soldiers would shoot citizens who strayed out of line or tried to make a break for the West.

"The Blackbird could travel at more than three times the speed of sound"

After World War Two, the US set up Project Shamrock and Project Minaret, espionage exercises to monitor all telegraph information entering and leaving the country. Despite this, there were a number of spies operating in the US for the Soviets, gathering information on nuclear weapons, military movements and new technologies.

Aerial reconnaissance continued to play a huge part in intelligence operations. The CIA located Soviet ballistic missiles using spy satellites under the Corona Program. After a CIA pilot was shot down while flying over the USSR in a U-2 spy plane in 1960, the US realised that continuing to use these aircraft was too risky. In response, the record-breaking SR-71 Blackbird was constructed. The Blackbird could travel at more than three times the speed of sound, and reach altitudes high enough to avoid radar detection. The reconnaissance jet even had special radar-absorbing black paint.





1 CIA training

Only the most successful recruits are selected to be agents. An intensive course including both physical and mental tasks will show who's capable of being a spy.



2 The life of a spy

To avoid arousing suspicion, you must create a believable persona and backstory. The finest agents appear to live completely ordinary lives.



3 Data collection

Your main objective is to determine the Soviets' intentions towards the US. The intelligence you gather could give your country a huge advantage.



4 Decryption skills

The best spies have a talent for code-breaking. Soviet intelligence agents encrypt their messages so you will have to decipher them to reveal any secret plans.



5 Break morale

With your spy persona, you have the ability to spread rumours behind enemy lines. Create fake news stories to cause unrest among citizens or the leadership.



6 Avoid capture at all costs

If you're caught, it's all over. Espionage is a serious offence during the Cold War, carrying the penalty of a long prison sentence or execution.

The 'Illegals Program'

In 2010, ten Russian agents were arrested in the US. Upon interrogation by the FBI, it was revealed that they had been active in the US for years as sleeper agents, spies who weren't always active but resided in the US if ever needed for duty. Known as 'Illegals', some of the spies posed as American citizens with fake names and backgrounds, and had normal jobs. They had been instructed to make contact with academics to obtain secret intelligence that they could report back to Russia. All ten of the spies were charged with conspiracy to act as an agent of a foreign government, and were released into Russian custody as part of a prisoner exchange.

Anna Chapman was arrested after an FBI operation exposed her as a sleeper agent



Spies wanted

How intelligence agencies operate in the internet age

Most of us share our lives with friends and family on social media, but this data creates problems if you want to be a spy. Intelligence agencies are struggling to operate effectively in a time where false identities and backstories are hard to create. Most people will leave traces of their real lives online, and facial recognition software can potentially use these traces to link an undercover agent to their true identity.

To try and combat this, the UK's Secret Intelligence Service (SIS, or MI6) were planning to hire nearly 1,000 new staff by 2020. In a statement, SIS chief Alex Younger explained: "The information revolution fundamentally changes our operating environment. In five years' time there will be two sorts of intelligence services – those that understand this fact and have prospered, and those that don't and haven't."

Vauxhall Cross in London has been the SIS's headquarters since 1994





The Siege of Tyre

Find out how Alexander the Great's relentless advance was halted by the determined defence of one city-state

Two years into their conquest of the Persian Empire in 332 BCE, the Macedonian Army faced one of its hardest challenges yet. As Alexander the Great had marched through Phoenicia, many towns, including Byblos, Beirut and Sidon had immediately surrendered. But the walled city of Tyre, an important Persian naval base, refused Alexander's demands to perform a sacrifice in the temple of Melqart, and he responded by placing the city under siege.

The city was located on an island nearly a kilometre out to sea and was surrounded by a thick, 40-metre-high wall. Nevertheless, having defeated the Persian king Darius III repeatedly on the battlefield, Alexander was feeling confident, even with only a small navy at his disposal. The Tyrians were dedicated to neutrality and safe within their walled city, they did not want to be embroiled in Macedon's bloody war against the Achaemenid Empire.

Enraged, Alexander demanded a surrender but the Tyrians refused to back down. After all negotiations had failed, he prepared his attack.

The city was clearly impregnable by normal methods of assault, so Alexander looked to alternative strategies for a breakthrough. It was decided that a fleet was required after all and raiding parties were sent out to muster one from surrounding areas. The addition of naval assaults, as well as the construction of a stone causeway, or

'mole', proved to be too much for the city and the walls were finally breached. In the brutal battle that followed, 10,000 residents were executed, while 30,000 more were forcibly sold into slavery. The victory was six months in the making, and proved to be one more example of Alexander's ruthless yet effective military tactics.

Tyrian evacuation

Sensing the coming storm, the city's women and children are evacuated to a colony on the nearby island of Carthage

Breaching the battlements

Heavy bombardment from catapults breaks down a section of the walls and infantry advance through the breach

Siege towers set ablaze

The 45-metre-high towers advance on the walls but Tyrian fire ships speed into the bay and ignite their wooden siege engines

Anatomy of a siege

How Alexander's army overcame the formidable defences of Tyre

The mole

Plundering stone and timber from the nearby ruins of Old Tyre, engineers construct a narrow causeway over the shallow water

Battle begins

The 60-metre-wide mole acts as a bridge as soldiers and wooden siege engines roll into view of the battlements

"Raiding parties were sent out to muster a fleet from surrounding areas"

Alexander the pharaoh

Tyre was the last Persian stronghold in Phoenicia to fall, and the road to Egypt then lay open to Alexander the Great. The young Macedonian had been brought up with tales of the splendour of Ancient Egypt and after witnessing the Great Pyramid with his own eyes, he sailed down the Nile to Memphis.

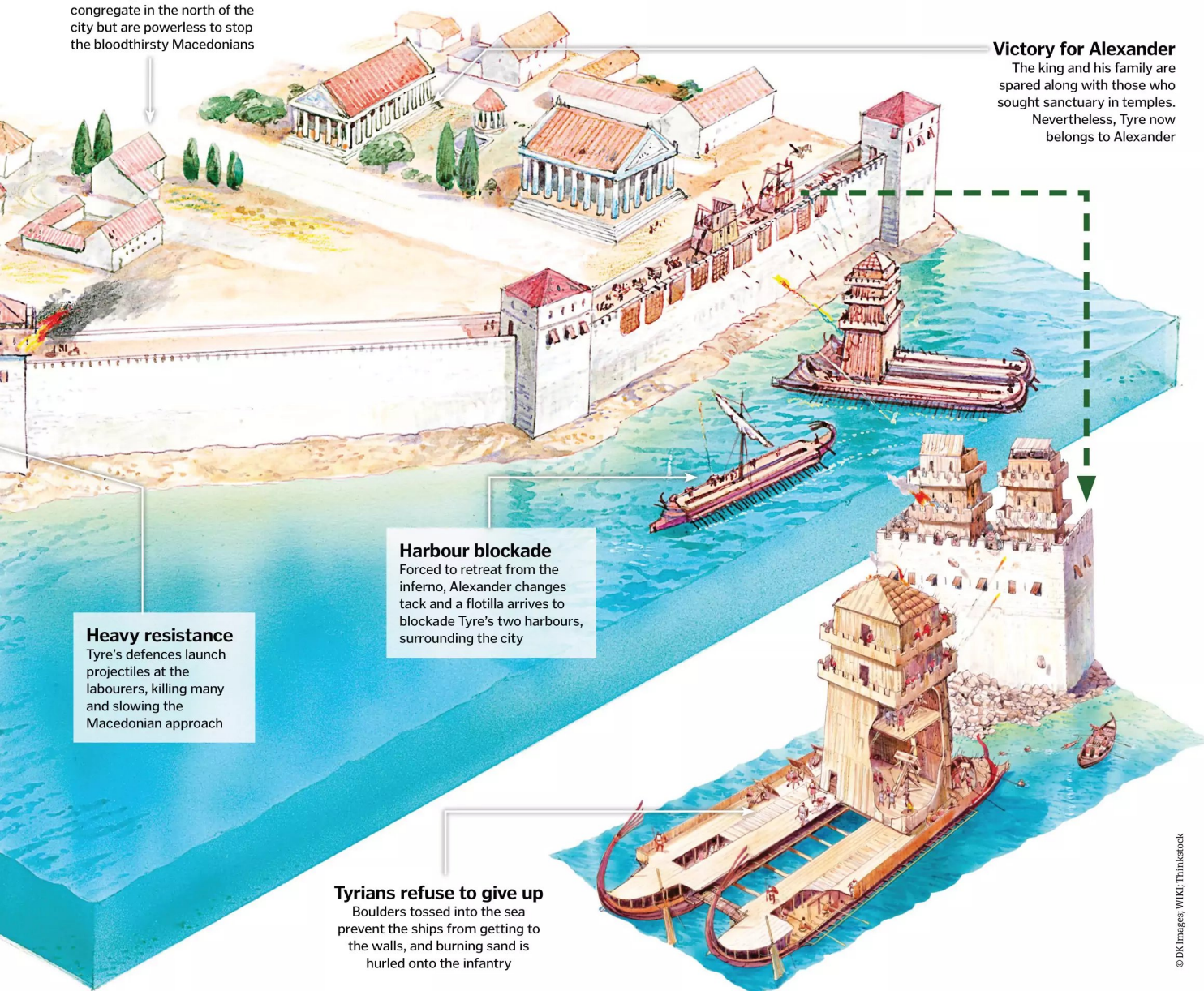
The Egyptians saw Alexander as their saviour, having liberated them from Persian rule after centuries of repression. Upon his arrival, Alexander was declared Pharaoh and began worshipping Egyptian gods as forms of Zeus. It was during this conquest that he began to seriously see himself as a demi-god as his ego took hold. After founding the city of Alexandria and naming it after himself, he left Egypt in 331 BCE and decisively triumphed over Darius and the Persians at the Battle of Gaugamela. Having been declared 'King of the Four Quarters of the World', Alexander continued his conquests, heading east to take eastern Iran and northern India. He died of malaria in 323 BCE, aged just 32.



Alexandria flourished as a port town, taking Tyre's place as the centre of trade and commerce in the region

Tyre's last stand

The last Tyrian defences congregate in the north of the city but are powerless to stop the bloodthirsty Macedonians



Victory for Alexander

The king and his family are spared along with those who sought sanctuary in temples. Nevertheless, Tyre now belongs to Alexander

Harbour blockade

Forced to retreat from the inferno, Alexander changes tack and a flotilla arrives to blockade Tyre's two harbours, surrounding the city

Heavy resistance

Tyre's defences launch projectiles at the labourers, killing many and slowing the Macedonian approach

Tyrians refuse to give up

Boulders tossed into the sea prevent the ships from getting to the walls, and burning sand is hurled onto the infantry

Brutal battering rams

How were these powerful siege engines built and used?

Battering rams were one of the most common pieces of siege equipment from antiquity right through to the Middle Ages, often granting offensive forces access to an enemy's fortified stronghold or city.

A typical battering ram consisted of a rectangular wheeled frame from which a large tree trunk was slung via ropes or chains. The suspended trunk would then be rocked backwards and forwards within the frame until it swung with great force. By placing an obstacle – such as a wooden gate – in the ram's path, it could transfer a vast amount of energy into the target, often shattering the defence.

However, for a ram to get up to speed, a team of soldiers was required to first place it in position and also control its swinging – both of which are difficult when under attack by ranged weapons. To counter this, battering rams often featured triangular wooden coverings stretched with wet animal hides. This shielding protected the soldiers from direct missile strikes and the risk of fire, with the hides extinguishing any flaming arrows.

The age of the battering ram came to a close largely due to the proliferation of gunpowder and explosives in the late-Middle Ages, with army sappers using these incendiary devices to bring down gates and walls much faster.

Roof

A wooden board covered with wet animal skins protected soldiers below from missiles and also snuffed out fire arrows

Chains

Due to the immense weight of the ramming trunk, thick rope or large metal chains were typically used to take most of the burden



Cap

The tree trunk was capped with a pointed steel plate. This helped prevent splitting in the ram when pounding through gates/doors

Grips

Bolted into the side of the trunk was a series of metal bars, which enabled the operators to better direct the ram and increase its swing

What other weapons were used in siege warfare?

Trebuchet

One of the most useful siege weapons ever to be created, the catapult-style trebuchet allowed an army to bombard a city's walls and interior buildings with huge stones, flaming balls of earth and even dead animals (the latter spreading disease and panic throughout the inhabitants). On the downside, trebuchets required a large team to operate effectively.



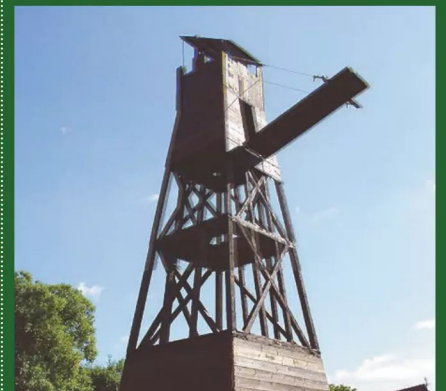
Ballista

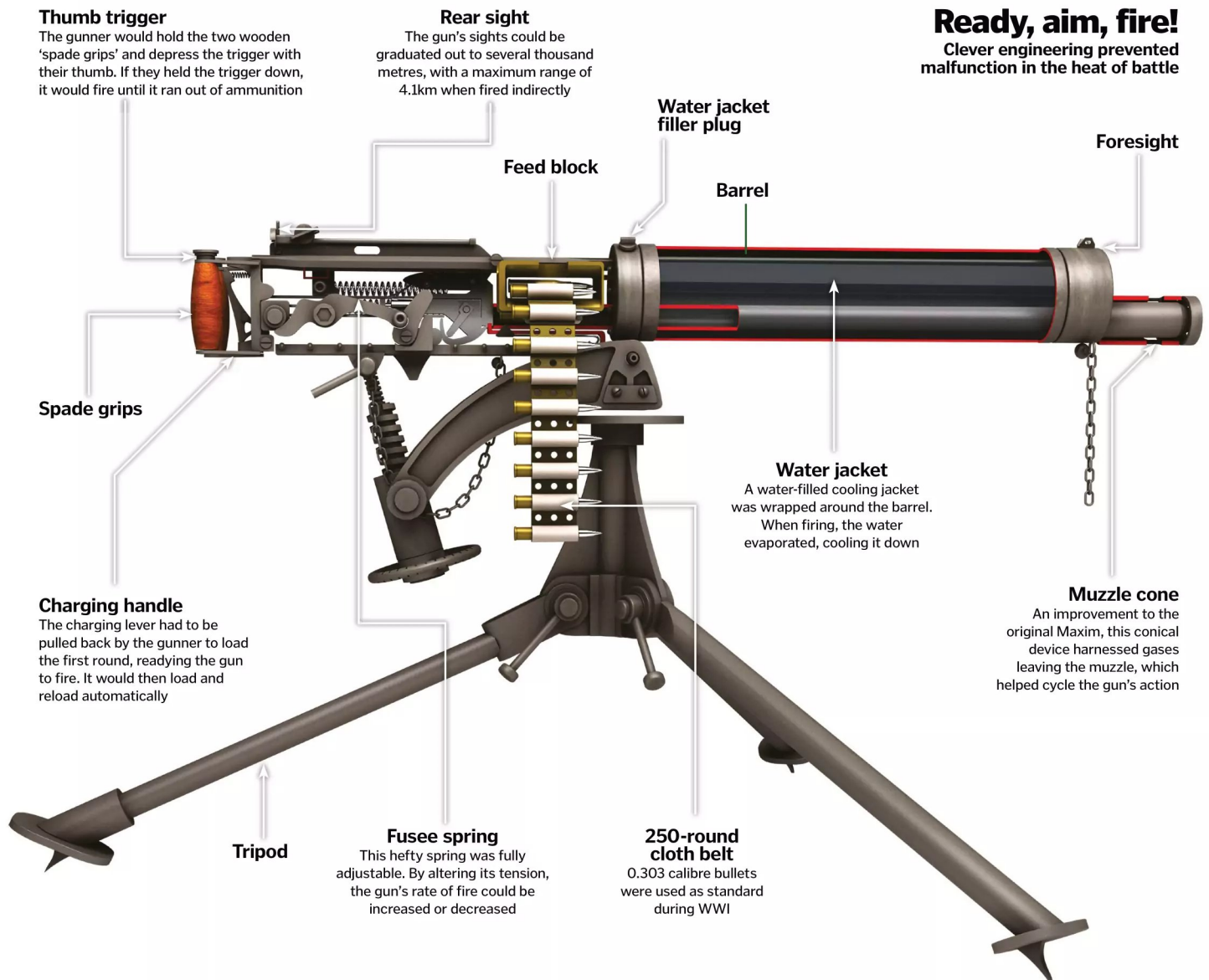
A large missile-throwing weapon, the ballista was an excellent choice when you wanted to disrupt infantry columns. Developed first by the Ancient Greeks, the ballista worked via torsion springs, with huge wooden spikes propelled at great speed when released over large distances. The ballista would be scaled down over the centuries until eventually it could be handheld.



Tower

A simple yet devastatingly effective siege weapon if used correctly, the tower was literally a mobile wooden turret on wheels that enabled troops to scale enemy walls in relative safety. After climbing up through the shielded internal cavity, soldiers would then be released with the dropping of a small drawbridge, enabling them to charge over enemy battlements.





WWI's Vickers-Maxim gun

Stare down the barrel of this deadly British weapon

The Vickers-Maxim machine gun obliterated battlefields, rattling off over 450 rounds a minute. It entered service in time to see action during World War I and served the British Army for more than 50 years.

The key to the design was that it used the power of the cartridge explosion to reload and re-cock the gun after each shot. This became known as a recoil system, as the forward force of the bullet produced an opposing force – the recoil. The force generated pushed the bolt and barrel backwards, while they were locked together. A small metal catch then unlocked the

two parts as they moved backwards, before the spring pushed the barrel forward again. The backward motion also ejected the used shell, and a new cartridge was automatically loaded into place from the ammunition belt. If the trigger was still depressed, the whole cycle started again and another shot would fire almost immediately.

Although the Vickers was rather heavy and required a team of six to operate, it was extremely reliable. During a British attack in 1916, it's estimated that ten Vickers fired more than one million rounds in just 12 hours.

Men from 5th (Scots) Parachute Battalion, 2nd Parachute Brigade, fire a Vickers machine gun from a rooftop in Athens in 1944



© WIKI



Meet the musketeers

One of the most popular military units for centuries, musketeers fought in battles and protected esteemed rulers all the way from France to India

Musketeers were an early form of soldier who were armed with muskets. They acted as a bridge unit between traditional infantry – which fought on foot and typically hand-to-hand with swords and other melee weapons – and dragoons, a type of light cavalry armed with long-ranged weapons. This granted them a level of versatility and flexibility most prized on the battlefield, with musketeer units typically reserved for the protection of nobility or, in many Western nations, royalty.

While musketeers as a unit are older (see 'Musketeer origins' boxout for details), they didn't emerge in Europe until the 16th century, with the concept only really taking off on a large scale in the early-17th century.

While this particular era was dominated by the French musketeers of the *Maison du Roi* (the Royal

Household) – upon which the fictional musketeers of Alexandre Dumas' *The Three Musketeers* are based – countries like Spain, Britain, Russia, Sweden, Poland and even India each developed their own musketeer units in this period and used them on the battlefield frequently.

Musketeers as a common military unit were largely phased out by the middle of the 19th century, with a number of new developments in firearms rendering the musket obsolete. With the introduction of the rifle – which could shoot both farther and much faster than the musket – the rifleman unit would emerge, negating the need for the greater speed afforded by the mounted musketeer.

This, combined with the decline of many dynasties throughout Europe – notably the *Ancien Régime* of France during the French Revolution – saw all musketeer units permanently disbanded.



A Prussian engraving of a French musketeer (right) from the reign of Louis XIV (1643-1715)

How to fire a musket step-by-step



1 Carry
While marching to position the musket should be carried over the shoulder,

with the firing rest secured in your off-hand.



2 Firing prep
When firing is ordered, the musket is filled with priming powder, charge

and ball, with the weapon held in a diagonal orientation.



3 Insert fuse
The match fuse should then be cocked in the matchlock and blown on,

ensuring at all times that the match doesn't extinguish.



4 Shoot
Draw up the musket while simultaneously securing the firing rest. Slot the musket in

the rest's support brace, aim and fire.



5 Withdraw
Bring the musket off its rest, draw it down to your side, then take the fuse off the

musket and await further instructions from superiors.

Uniform of a musketeer

Check out the essential kit worn by famed musketeer captain, Comte d'Artagnan

Bandolier

Bandoliers (a pocketed belt) and ammunition pouches/bags were a common accessory for musketeers, so they were always well supplied on the battlefield. These belts were strapped around the waist or chest

Musket

The musketeer's primary weapon, the musket was deadly, albeit cumbersome to use. Its slow reload rate restricted use to four shots per minute at best

Cape

A feature associated more with earlier iterations of musketeers, the cape offered some protection from the elements while travelling

Musketeer origins

Unlike the musketeers of the Maison du Roi – the Royal Household of France – who were founded in 1622 during the reign of Louis XIII, musketeers had already been operating across the other side of the world in China since the 14th century. Indeed, through the Ming Dynasty (1368-1644) no national army was complete without multiple musketeer divisions, with soldiers armed with matchlock muskets. Surviving texts indicate that these musketeers fired in lines and typically from a kneeling position. This development of the concept of musketeers in China stemmed from their invention and mastery of gunpowder, with the musket revolutionising traditional forms of combat.

Hat

Musketeers started off in the West wearing simply ornate hats, but by the early-19th century these evolved into metal helmets. They did remain decorative though, often with large feathered plumes attached

Tunic

Considerably more elaborate than standard infantry, musketeer tunics and – in later periods – cuirasses, favoured manoeuvrability over armoured protection

Holdall

As musketeers were on the road during much of their military service, each carried their own holdall to store food and personal belongings

Sword

As musketeers were trained to fight both on horseback like dragoons and on foot like infantry, they were also equipped with a sword for hand-to-hand engagements

Boots

Boots were an important part of the musketeer's uniform, both communicating their prestigious position and providing good support on the ground and on horseback (some had spurs attached)

"The musket was deadly, albeit cumbersome to use"



Inside the Manhattan Project

In 1945, America unleashed the most powerful weapon the world had ever seen

The word atom means 'uncuttable', but in 1938 German scientists achieved the unthinkable. They split an atom into pieces, triggering an intensive period of research that would change the world forever.

Splitting the atom, or nuclear fission, was achieved by shooting neutrons at uranium. As the particles slammed into the atoms, their nuclei broke apart, creating lighter elements and releasing more neutrons in the process. If these neutrons could be harnessed, they could be used to split even more uranium atoms, triggering a chain reaction that could become powerful enough to be used as a weapon. And, as World War II dawned, physicists were afraid that the Nazis would do just that.

Several scientists had fled fascism in Europe and arrived on American shores, and among them were Leo Szilard, Albert Einstein and

Enrico Fermi. Szilard wanted to warn the president about the new discovery, but he was a junior researcher and needed a more senior scientist to back him up, so he asked colleague Edward Teller to take him to see Einstein, who then alerted President Theodore Roosevelt.

Roosevelt formed an advisory committee on uranium, but he was distracted by the war and it wasn't until 1941 that he really sat up and took notice. That was the year that Japan attacked Pearl Harbour, killing over 2,000 American soldiers in a brutal aerial ambush.

Headquartered in New York City and under the name of the Manhattan Project, Lieutenant General Leslie R Groves assumed control of atomic research. His team was given just \$6,000 to investigate atomic warfare, and eminent physicist Enrico Fermi began work on the first phase. No one thought they would succeed.

Fermi had escaped Italy when he went to Sweden to collect his Nobel Prize; rather than return home, he fled to the US with his wife. As the Manhattan Project began, he focused his efforts on getting a nuclear chain reaction working, and with Szilard's help he built the world's first nuclear reactor in a squash court under the stadium at the University of Chicago.

To sustain a nuclear chain reaction, they needed to slow the neutrons down so that they could collide with more uranium nuclei and split them open. They did this by embedding uranium spheres in layer upon layer of graphite. Finally, in 1942, they succeeded in getting a chain reaction going, and the government started to pour money into research.

The army bought land in the desert at Los Alamos in New Mexico under the pretence that they needed a new demolition range. The new

facility was put under the command of physics professor Robert Oppenheimer, and the team started working out how much fuel they would need to build their bomb.

Uranium ore contains different isotopes of the radioactive element; the atoms of these variants have different numbers of neutrons. Most uranium is in the form of uranium-238, but to build a bomb the scientists needed uranium-235, so they needed a way to separate them. The calculations for how much fuel they would need were little more than estimates, but when Oppenheimer and his team asked for 200 kilograms of uranium (ten times more than they ended up using), President Roosevelt approved \$500 million of extra funding.

The first separation devices for creating uranium fuel were designed by Ernest Lawrence at Berkeley, California. Known as calutrons, the machines were scaled-up mass spectrometers, which send atoms whizzing past a magnet. Uranium-235 is ever so slightly lighter than uranium-238, and the lighter an atom is, the more the magnet will bend its path, allowing the two to be neatly separated.

The process was painstakingly slow; each calutron structure could only produce ten grams of uranium-235 a day. So they built a dedicated facility called the Y-12 Uranium Enrichment Plant at Oak Ridge in Tennessee, which contained over 1,150 of them. There was no time to test the tech on a small scale, and when they first switched Y-12 on, its magnets reportedly pulled the nails out of the walls. However, once it

was up and running, the plant attracted 75,000 workers, and by the end of the war Oak Ridge was the fifth largest town in Tennessee.

Calutrons alone weren't going to be able to produce enough uranium to build a bomb, so the Manhattan Project scientists employed a second enrichment method to generate even more fuel. Gaseous diffusion – developed in the UK in the 1940s – worked by combining uranium with fluorine to make uranium hexafluoride gas. This gas was then passed through a barrier studded with microscopic holes, barely large enough to allow the molecules through. The molecules containing the smaller uranium-235 isotope squeezed past slightly faster on average, allowing them to be collected. 300,000 square metres of the barrier were constructed at the K25 plant in Tennessee in 1943.

At its peak, the production of nuclear fuel for the programme was consuming a tenth of the energy produced in the US. And within the space of two years the Manhattan Project had expanded to become one of the largest scientific

Uranium ore must be heavily processed to extract the right isotope needed to make a bomb



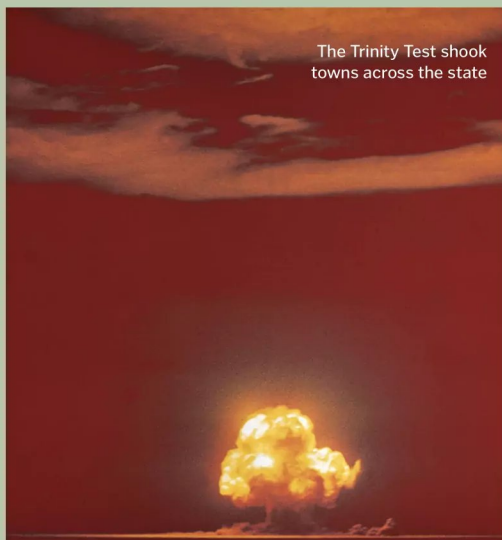
"There was no time to test the tech on a small scale"

The first atom bomb

On 16 July 1945, the world changed forever. In the Trinity test, a 20-kiloton bomb known as 'The Gadget' was detonated in the Jornada del Muerto Desert in New Mexico, throwing a vast mushroom cloud into the air and turning the ground beneath to glass.

The Gadget was based on the same design as the Fat Man, the bomb that would later be detonated over the city of Nagasaki. It contained plutonium encased in explosives, designed to compress when it was triggered, kick-starting a nuclear chain reaction.

No one knew what would happen when an atom bomb went off, so soldiers were placed in the surrounding towns to help with an evacuation if it all went wrong. But the trial was a success, and less than a month later the bombs were dropped for real.



The Trinity Test shook towns across the state

The brains behind the bomb



Leo Szilard

Hungarian-born physicist Szilard was a close friend of Einstein and the catalyst of the Manhattan Project. He eventually led a petition against use of the bomb on cities.



Robert Oppenheimer

A theoretical physicist and head of the 3,000-strong team of scientists at Los Alamos, Oppenheimer later opposed the development of the hydrogen bomb.



Enrico Fermi

Awarded a Nobel Prize in 1938 for his work on radioactivity, Italian physicist Fermi led the beginning of the Manhattan Project. He constructed the first ever nuclear reactor.



Otto Hahn

German chemist Hahn discovered nuclear fission and was awarded a Nobel Prize. He was not a part of the Manhattan Project, but his science formed the basis of the bomb.



Edward Teller

Hungarian-American Teller led a team in the theoretical physics division at Los Alamos. A strong supporter of nuclear weapons, he is known as 'the father of the hydrogen bomb'.



Hans Bethe

Nobel Prize winner, Bethe was chief of theoretical physics at Los Alamos. He worked with Teller to develop the hydrogen bomb but later campaigned for nuclear disarmament.



Seth Neddermeyer

Neddermeyer was an American physicist and the mastermind behind the implosion design of the Fat Man atomic bomb that was dropped on the Japanese city of Nagasaki.



James Chadwick

Chadwick was a Nobel Prize-winning English physicist who discovered neutrons. He led the British Mission collaboration with the Manhattan Project.



undertakings ever attempted, spanning several cities and employing tens of thousands of people from the areas of military, science and government. But the scientists still didn't know if their bombs would work.

Creating enough uranium for even one bomb was proving challenging enough, so there would be no extra fuel left over for a test, but in 1941, plutonium was discovered. This human-made radioactive element could be produced by irradiating uranium in nuclear reactors, and it

could potentially fuel a second bomb. Scientists in Chicago designed reactors to generate plutonium, and over 60,000 construction workers were set to the task of building a new plant in the desert at Hanford in Washington.

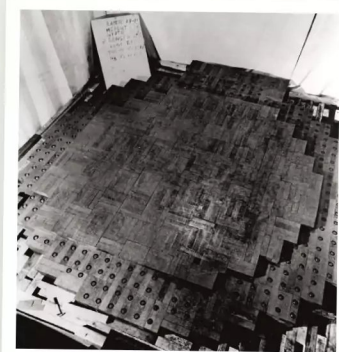
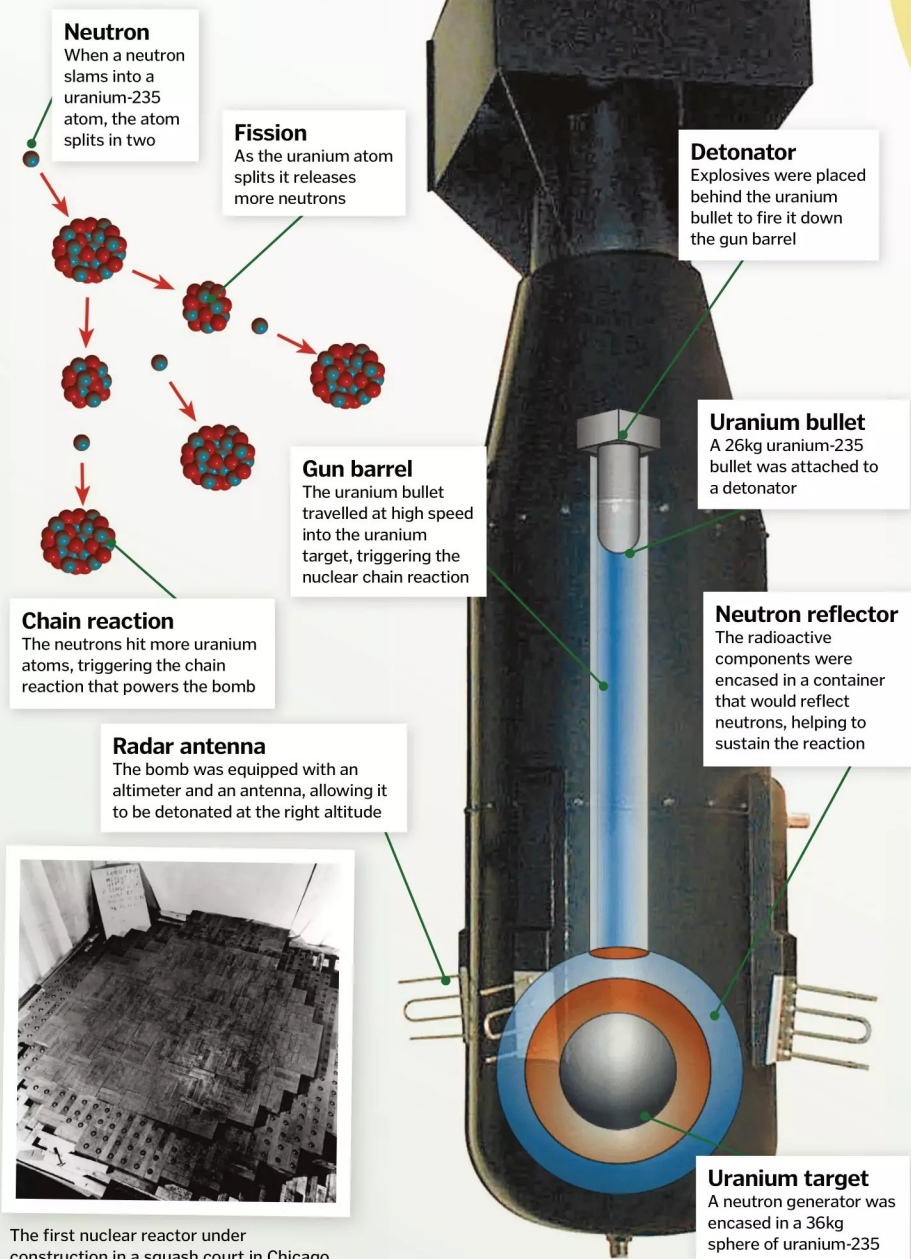
For the uranium bomb – later named Little Boy – the scientists were basing their design on a gun, firing one chunk of uranium into another to set off the chain reaction, but for the plutonium bomb they devised an outer shell of explosives that would detonate around a plutonium core.

The shockwaves would push the plutonium atoms together, triggering the chain reaction.

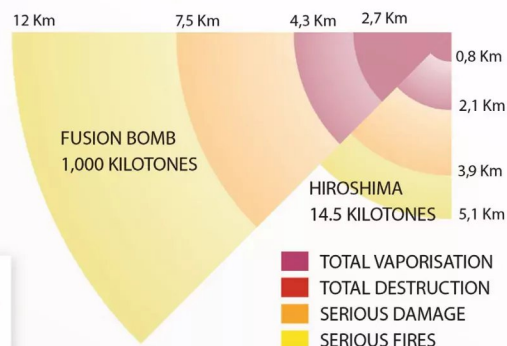
On 12 April, 1945, President Roosevelt died, and a month later, Nazi forces surrendered, but Japan refused to end the war, and America's project to develop their atomic bombs continued. President Truman made the decision to drop the bombs on 1 June that year, and in July they performed the first test on American soil, detonating a replica of the plutonium bomb - Fat Man - and releasing a blast equivalent to 20,000

The Little Boy

The bomb dropped on Hiroshima was a 'gun-type' design



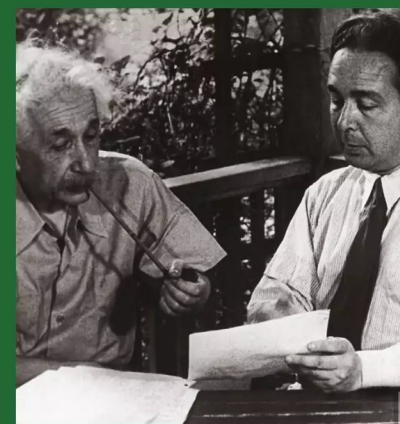
The first nuclear reactor under construction in a squash court in Chicago



Trying to stop the bomb

Physicist and inventor Leo Szilard had been the catalyst for the start of the Manhattan Project, but by 1945 he and many other scientists had become seriously concerned about the bombs that they'd helped to create. Szilard penned a petition to the president which read, "Atomic bombs are primarily a means for the ruthless annihilation of cities... a nation which sets the precedent of using these newly liberated forces of nature for purposes of destruction may have to bear the responsibility of opening the door to an era of devastation on an unimaginable scale."

The petition was signed by 70 scientists working on the Manhattan Project, but in April of 1945 President Roosevelt died. Szilard didn't know how to get the message to the new president, and Truman never saw it before the bombs fell.



Leo Szilard with Albert Einstein before the start of the Manhattan Project

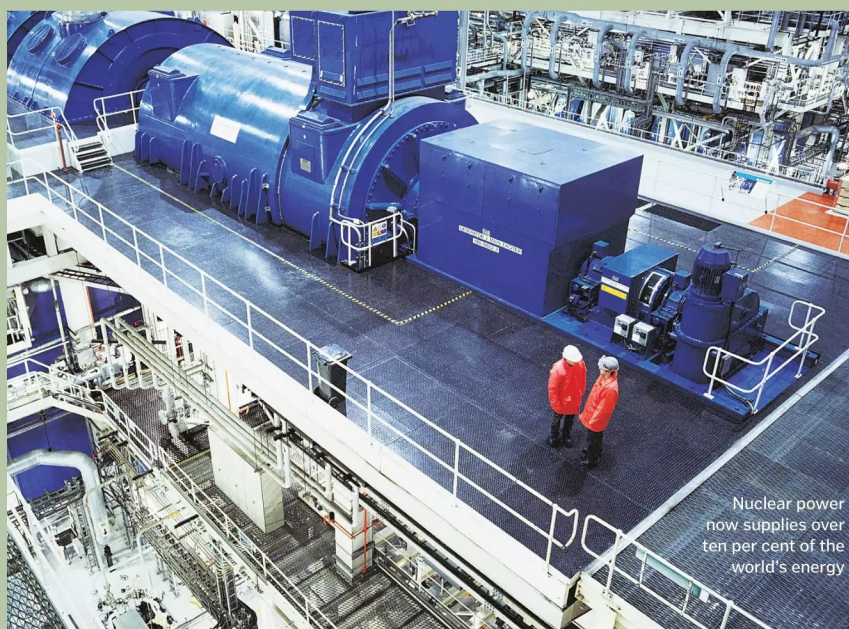


tons of TNT. This was right at the upper end of their estimates, and it turned the desert sand into glass.

On 6 August 1945, Paul Tibbets boarded the Enola Gay, named after his mother, and flew over Hiroshima with Little Boy. It had taken 120,000 people and over \$2 billion to develop the atomic bombs, and within moments 90 per cent of the city was flattened and 150,000 people were killed by the blast or subsequent radiation sickness. Two days later, Fat Man was detonated over Nagasaki, killing a further 75,000. Japan surrendered on 15 August 1945.

Oppenheimer, who led the Manhattan Project said, "We knew the world would not be the same. A few people laughed, a few people cried, most people were silent. I remembered the line from the Hindu scripture, the Bhagavad-Gita. Vishnu is trying to persuade the prince that he should do his duty, and to impress him takes on his multi-armed form and says, 'Now I am become Death, the destroyer of worlds.' I suppose we all thought that, one way or another."

"We knew the world would not be the same" – Robert Oppenheimer



The Manhattan Project's legacy

After the end of the Second World War, America continued to conduct atomic tests. The world had never before seen a weapon capable of such rapid and complete destruction, and as the atomic age dawned, several countries joined the nuclear arms race, stockpiling their own weapons to deter attacks from other nuclear states.

The Soviet Union, using information leaked by spy Klaus Fuchs, tested their atom bomb for the first time in Kazakhstan in 1949. The UK detonated the Hurricane in 1952, France joined in with Blue Gerbil in 1960, and China did their first test in 1964.

America also rushed to develop the hydrogen bomb, which they detonated in 1952 in the Pacific Ocean, completely vapourising the island of Elugelab. And, using more information from Fuchs, the Soviets designed their own, culminating in a 58 megaton blast in 1961.

In 1968, the US, USSR and UK agreed to a Non-Proliferation Treaty to limit the spread of nuclear weapons. They also encouraged the sharing of peaceful nuclear technology across the world, helping positive new developments like nuclear power and nuclear medicine to reach as many people as possible.



Close up of the tubes that fed uranium into the Hanford reactor



Sikorsky MH-60 Black Hawk

Designed for special operations in hostile environments, this was a new kind of war machine, built for a new kind of battlefield

From the chaotic skies over Somalia during the Battle of Mogadishu in 1993, to the covert operation to kill Osama Bin Laden in 2011, Black Hawk helicopters are among the deadliest, most effective tools available to any modern military. After its experiences in the Vietnam War in the 1960s and 70s, the US military knew just how essential it was to have tough, multi-role helicopters available. Not only were these aircraft useful for rapidly transporting combat personnel to and from battlefields, they could even remain on the front line to provide direct support. However, the existing Huey helicopters were out of date.

Two US companies, Boeing Vertol and Sikorsky, went head-to-head with their rival designs for the new combat helicopter, with the latter finally winning the contract with its S-70 prototype. Since the model first took to the skies in 1974, a huge number of variants have gone into production, each with its own specific role to play in a combat zone. For instance, the secretive 'MH-X' version – used during the mission to kill Al-Qaeda's chief – was rumoured to be equipped with stealth technology, making it almost undetectable to radar.

The MH-60 variant seen here was developed from the standard UH-60 Black Hawk for use during special operations. The machine's effective range was greatly increased with the addition of a more efficient fuel tank, the installation of systems for aerial refuelling, and the improvement of the craft's overall survivability. It was during a special operation that these assets would be put to the ultimate test, an incident known as Black Hawk Down.



The Black Hawk is capable of carrying a range of weaponry, and will often house a door gunner for protection in hostile environments

Inside a Black Hawk

The high-powered tech behind the MH-60 military machine

"Black Hawk helicopters are among the deadliest and most effective tools available to any modern military"

Machine guns

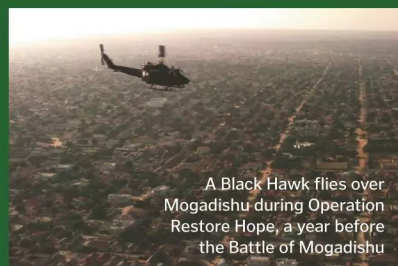
Two electrically powered M134 Miniguns, capable of firing a combined 12,000 rounds per minute, can be mounted on the aircraft

Optional extras

Black Hawks can be fitted with Hellfire anti-tank missiles and rocket pods, as well as additional fuel tanks for long-haul missions

The Battle of Mogadishu

On 3 October 1993, American Rangers flew into Mogadishu, the capital of Somalia, to capture a wanted terrorist leader. They swooped down on the target's base in a convoy of helicopters, with MH-60 Black Hawks hovering overhead to provide support. However, when two of these aircraft came under fire, they crash-landed into the maze of streets and alleyways below. What was supposed to be a smooth operation soon turned into chaos as soldiers battled through the streets to reach the downed aircraft and their stricken crew. The ensuing battle is now most famously known as Black Hawk Down, due to the 1999 book of the same name, which was adapted into the 2001 Oscar-winning film.



A Black Hawk flies over Mogadishu during Operation Restore Hope, a year before the Battle of Mogadishu

Twin engines

Two General Electric engines pack a combined 3,988 shaft horsepower, enabling the aircraft to reach a top speed of 280km/h



The use of night-vision (infrared) technology enables pilots to safely conduct special operations in total darkness

Safety features

The fuel tank, landing gear and body frame are all reinforced to protect the crew in the event of a crash. Even the pilots' seats are designed to absorb and nullify any critical impact

Radar

As well as GPS capability, the MH-60 is fitted with multi-mode radar capable of tracking the terrain below, even in poor weather conditions

Passengers

Up to 18 personnel can be transported in the rear of the aircraft, which has an operational range of over 2,200km

Night vision

A forward looking infra-red (FLIR) video camera pod captures the surrounding environment and relays it to the pilot, enabling safe flight in total darkness



Medieval
writing
092



INDUSTRY & INVENTION



086 **Gruesome inventions**
Tour some of history's most barbaric inventions

092 **First hearing aids**
How did we improve hearing before batteries?

092 **Medieval writing**
How to make a quill

093 **The birth of blue jeans**
How two visionary immigrants created an American classic

094 **The Colossus computer**
Get to know the story behind the first ever programmable digital computer

096 **Rack-and-pinion railways**
Unique transit systems that scale steep mountains



086
Gruesome inventions

084



The birth of
blue jeans
093



098 **Accidental discoveries**
Dive deep into the discoveries that changed the world

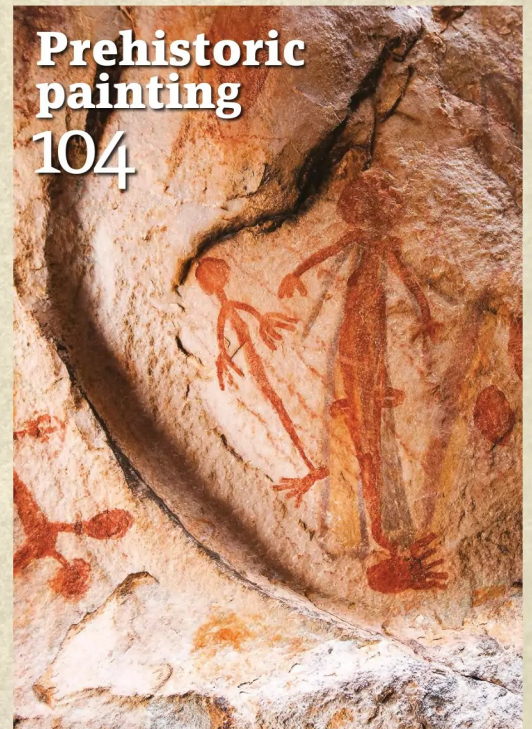
102 **The Antikythera mechanism**
Discover the ancient scientific device that calculated the locations of stars and planets

103 **The corvus**
The invention that turned the tide for the Romans during their first war at sea

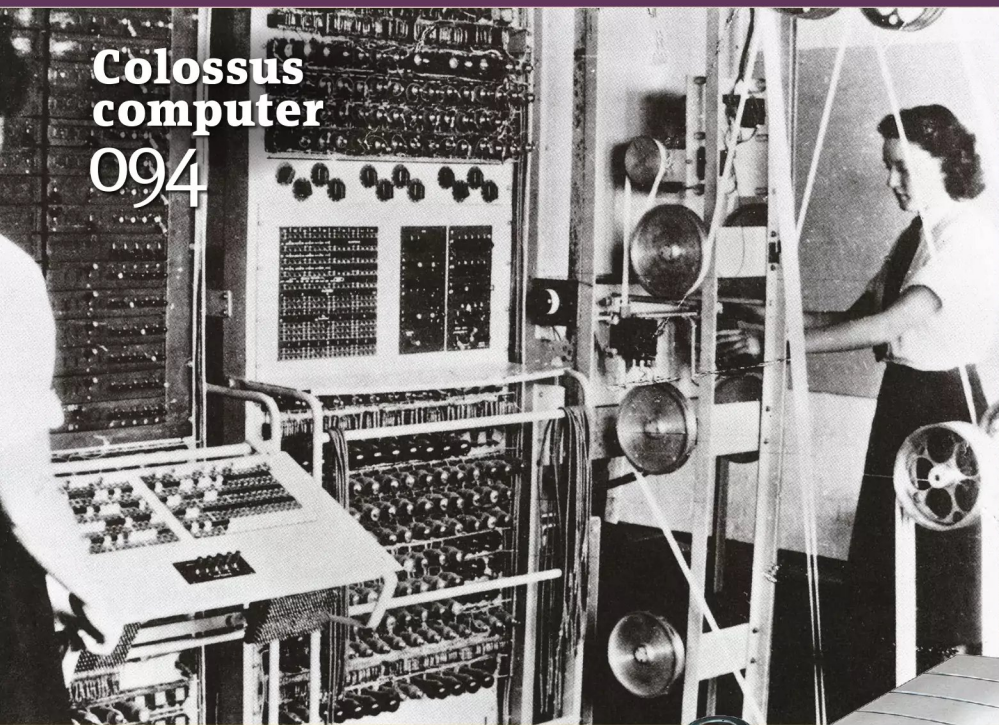
103 **Automatic doors of the ancient world**
Discover the world's first self-opening temple doors

104 **Prehistoric painting**
Artistic insights from our Paleolithic ancestors

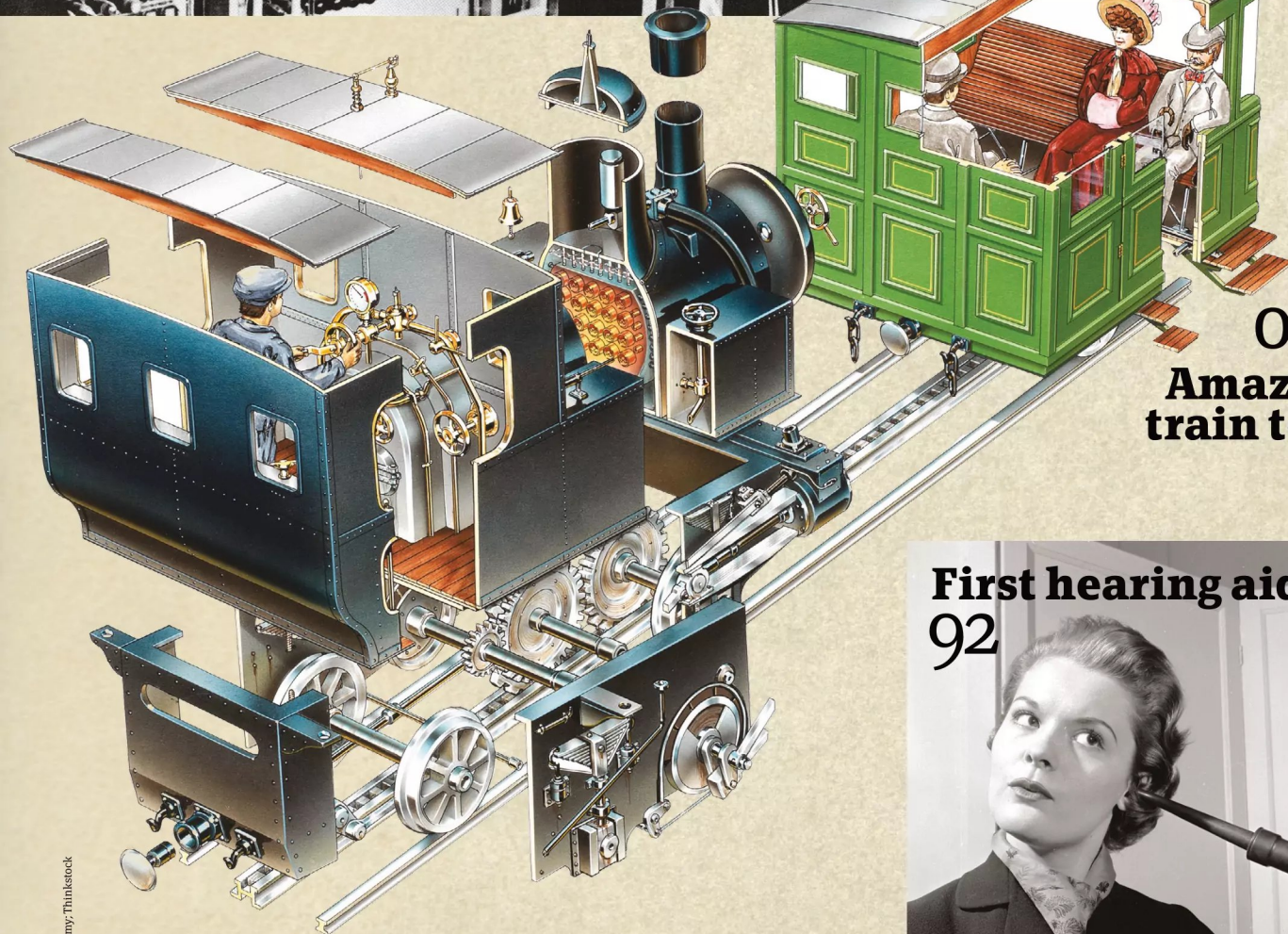
Prehistoric
painting
104



**Colossus
computer**
094



**098
Great accidental
discoveries**



**096
Amazing
train tech**

First hearing aids
92





History's most gruesome inventions

From brutal torture devices to bizarre medical treatments, these terrifying contraptions reveal a darker side of innovation

From the wheel to the World Wide Web, we have invented some truly groundbreaking things during our time on Earth. Yet throughout history, inventors have also been known to put their skills to use in horrifying ways, creating contraptions that have caused unimaginable suffering.

In the past, if you committed a terrible crime, a punishment much worse than a long prison sentence often awaited you. From boiling people alive to sawing them in half, execution methods

were often developed to be as cruel as possible. These gruesome events were usually carried out in public to deter others from committing the same crime.

But even if you weren't sentenced to death, there were plenty of ghastly implements that could be used to torture you instead. Typically used to extract a confession or information about accomplices, torture was popular in medieval times, with the screams of victims echoing from castle dungeons across Europe.

War has also inspired a selection of horrific innovations. While guns and bombs killed instantly, chemical weapons could draw out death for several agonising days – thankfully, this form of warfare is now prohibited.

We are also lucky that some medical devices from history are no longer used. Despite being designed with good intentions, many medieval procedures were truly stomach-churning, making a trip to the doctor quite the ordeal. So be grateful these inventions are before your time...

The brazen bull

Turning the screams of the dying into the roar of a beast

Through the trap door

The victim is placed inside the hollow brass bull through a trap door in its back or side, and locked in

Light the fire

The door is closed and a fire is lit beneath the belly of the bull

Hear the bull roar

The victim's screams leave through the nostrils of the bull, sounding like the bellowing roar of the beast

Modify their screams

A series of pipes in the bull's head amplify and distort the victim's cries

Slow cooking

The heat from the fire turns the bull into an oven, slowly roasting the victim inside

One of the most brutal methods of execution ever created took the form of a hollow bull statue. Invented in Ancient Greece by Perillus, a bronze worker in Athens, it was given as a gift to a cruel tyrant named Phalaris of Agrigentum. As well as roasting criminals

alive, the device doubled as a musical instrument, converting the victim's desperate cries into what Perillus described as "the tenderest, most pathetic, most melodious of bellowings". Distrustful of the inventor's claims, Phalaris ordered Perillus to climb

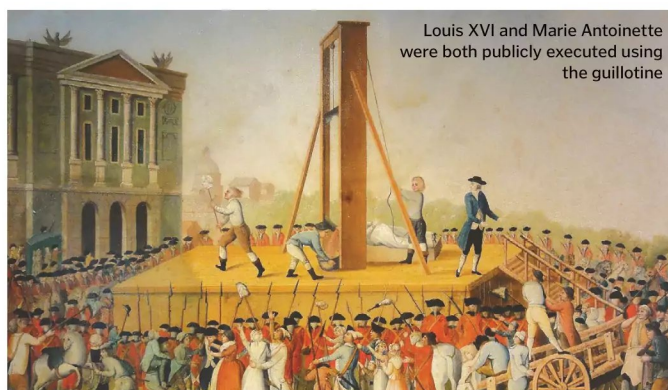
inside and prove the device's musical capabilities. As soon as he was inside, Phalaris shut the door and lit a fire beneath. However, rather than letting him die at the hands of his own creation, Phalaris had him removed and thrown off a cliff instead.

Illustration by Tom Connell / Art Agency

Crucifixion

Devised over 2,500 years ago as punishment for the most serious crimes, crucifixion would kill victims in a horribly drawn-out and painful way. With their wrists and feet nailed or tightly bound to a cross, and their legs broken by the executioners to speed up death, the victim's weight would be transferred to their arms. This would gradually pull the shoulders and elbows out of their sockets, leaving the chest to bear the weight. Although inhaling would still be possible, exhaling would be difficult and the victim would eventually suffocate due to a lack of oxygen. This excruciating process could take 24 hours.

Crucifixion would lead to suffocation and multiple organ failure



Guillotine

Although beheading methods had already been around for centuries, in 1789 French physician Dr Joseph Guillotin proposed a much more efficient and humane device for decapitation. When the executioner released the rope holding the guillotine's weighted blade in place, it would drop onto the victim's neck, killing them in a fraction of a second. This helped to eliminate the human error that was common with axe and sword beheadings, sometimes requiring multiple swings to fully remove the head. Although quick, guillotine executions were popular spectator events during the French Revolution and the guillotine operators became national celebrities.

Electric chair

Electrocution was adopted as a quicker and supposedly less painful method of execution than hanging in the 1880s. The victim has their head and one calf shaved to reduce resistance to electricity before being strapped in across their waist, arms and legs. A moistened sponge is placed on their head and an electrode in the shape of a metal skullcap is secured on top. Another electrode is attached to their shaved leg before the power is switched on. 2,000 volts pass through their body, paralyzing the respiratory system and causing cardiac arrest.

Electrocution is still used as a method of execution in some US states





Inside a torture chamber

The terrifying devices that inflicted intense pain

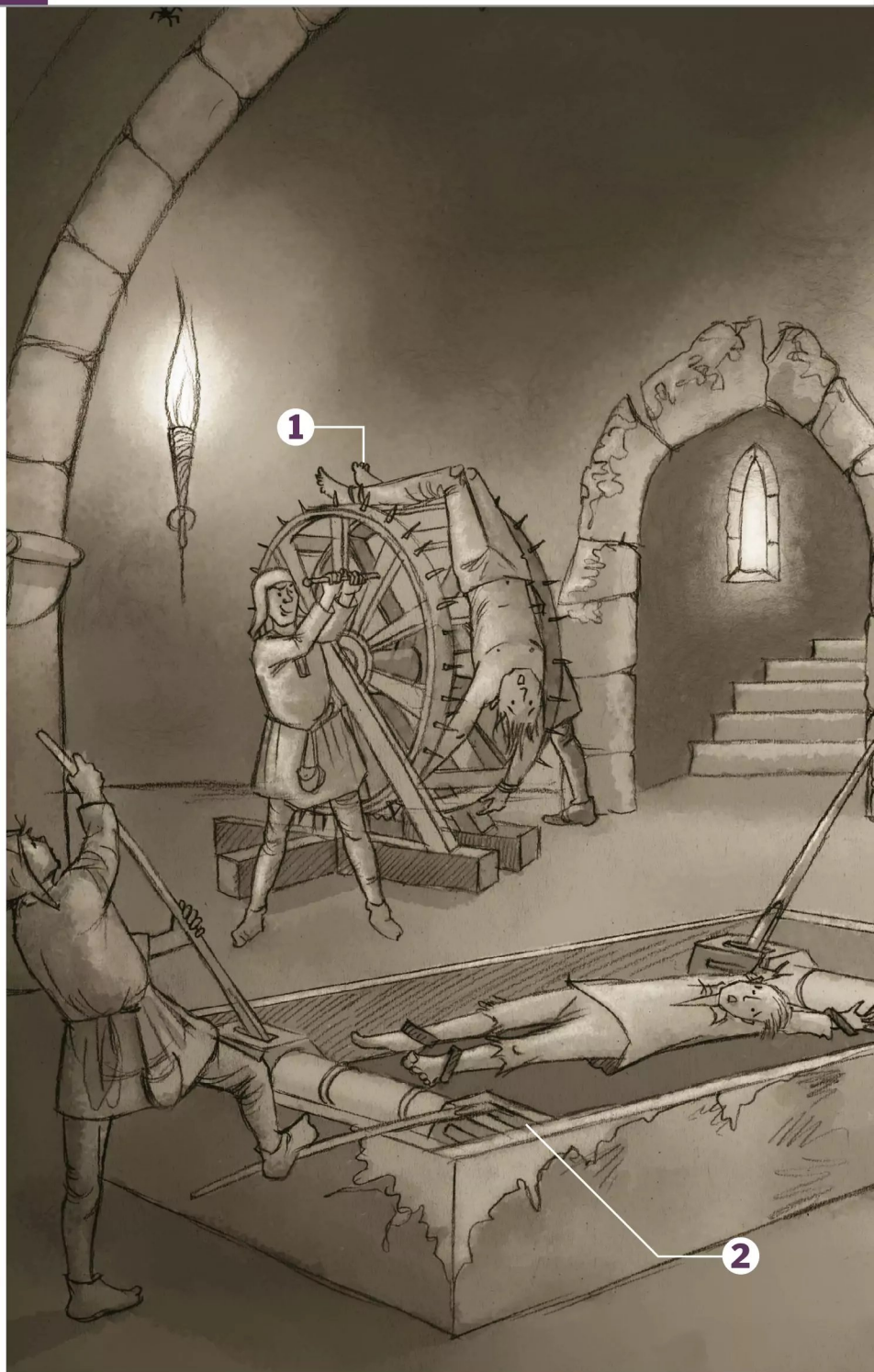
Torture has been used as a method of punishment and interrogation for centuries, with the Ancient Greeks and Romans regularly torturing criminals as part of their justice system. However, by the Middle Ages torture had become particularly prevalent, especially in response to crimes of treason. If you had been disloyal to the sovereign and your country, a whole plethora of horrifying torture devices awaited you.

Torture was usually conducted in secret, with most medieval castles featuring an underground dungeon in which these diabolical deeds took place. A great deal of ingenuity and artistic skill went into developing instruments that would inflict the maximum amount of pain. Often simply threatening to use one on a person was enough to get them to confess, while others would quickly give in after seeing it used on a fellow prisoner. Some torture devices were

“Often simply threatening to use torture on a person was enough to get them to confess”

designed to only inflict pain, but others would result in a slow, drawn-out death that prolonged suffering until the victim drew their last breath.

However, even if a prisoner was lucky enough to survive the torture, they were usually left severely disfigured and often had to be carried to their resulting trial as they could no longer walk on their own. From the mid-17th century onwards, torture became much less common as there was much speculation about its effectiveness. Many prisoners would say anything to end their suffering, so it often produced inaccurate information or false confessions. It wasn't until 1948 that the United Nations General Assembly adopted the Universal Declaration of Human Rights, banning the use of torture.



1 Breaking wheel

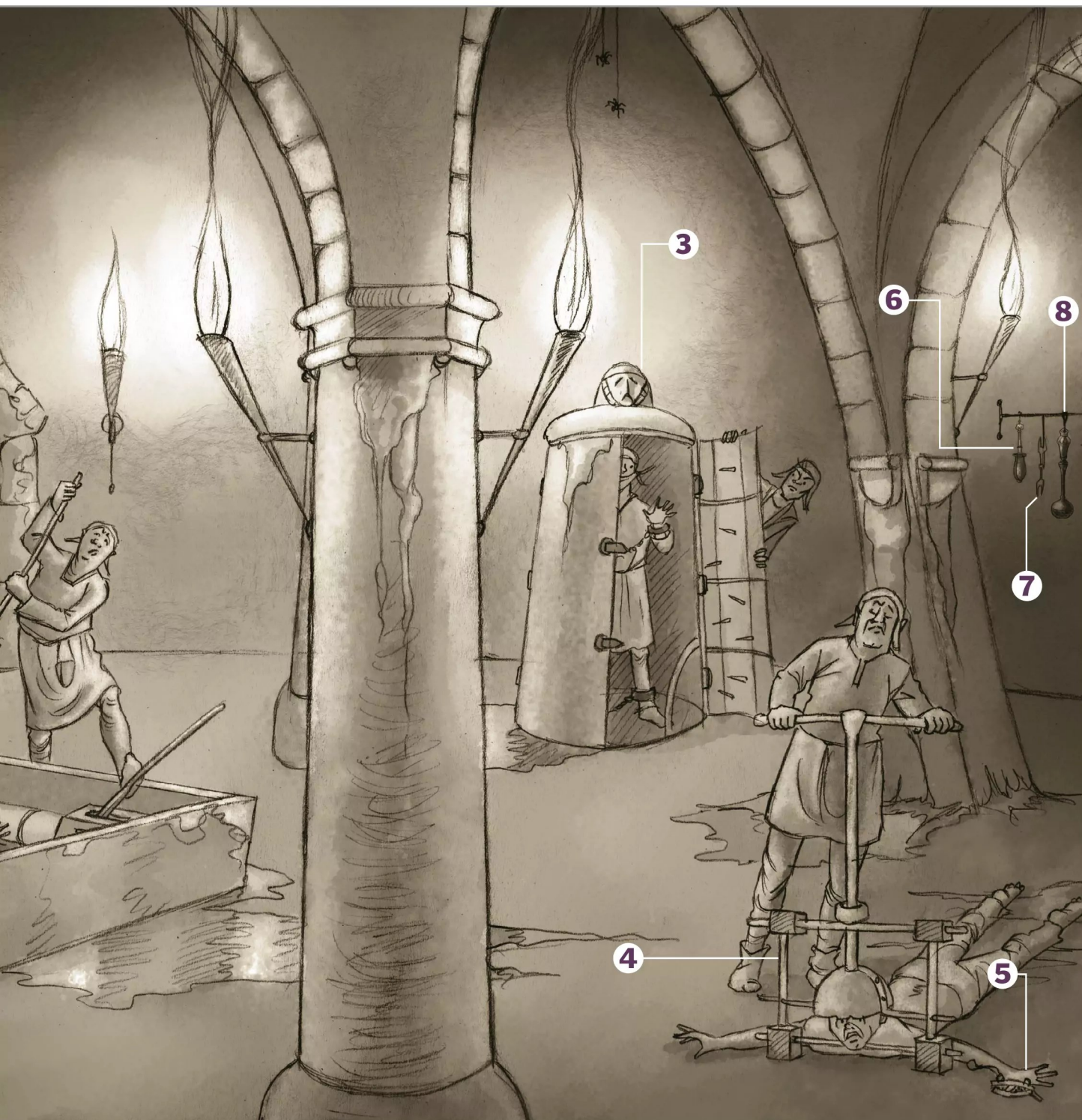
With the victim's limbs tied to the spokes of this large wooden wheel, it would be slowly revolved. As it spun, the executioner would bludgeon the victim's arms and legs with an iron hammer, shattering their bones one by one. If the victim survived this, they were placed on top of a large pole so birds could peck at their body until they eventually died of dehydration, which could take several days.

2 The rack

With their hands and feet tied to rollers at each end of the wooden frame, the victim would be subjected to brutal interrogation. If they failed to confess or give up the information the torturer was looking for, a crank would be turned to rotate the rollers. This would pull on the ropes, gradually and painfully stretching the victim's body, eventually dislocating their limbs.

3 Iron maiden

A series of menacing spikes protruded from the interior of this iron chamber. With the victim inside, the door was closed slowly, causing the strategically placed spikes to pierce the body. However, the spikes were not long enough to be instantly fatal. Instead, the victim would be left to slowly bleed to death.



4 Head crusher

With the victim's chin placed over the bottom bar and their head beneath the metal cap, the executioner would slowly turn the screw to bring the two together, only stopping if the victim gave the right answers. As the victim's head was crushed, their teeth would shatter into their jaw and their eyes would pop out from their sockets.

5 Thumb-screws

Used as punishment or a method of extracting information, the victim's fingers, thumbs or toes were placed between two horizontal metal bars. When the screw was turned, the two bars were pressed together, crushing the digits inside. Some thumbscrews even featured metal spikes on the bars to increase the pain.

6 Choke pear

Also known as the 'pear of anguish', this device was inserted into one of the victim's orifices, such as their mouth. When the key or crank was turned, the 'petals' of the pear-shaped end would slowly open up, painfully mutilating the victim's insides, but not causing death.

7 Heretic's fork

Usually reserved for blasphemers, this metal rod with two prongs at either end was attached to a leather strap around the victim's neck. One end would pierce their chin, while the other dug into their sternum, causing immense pain if they attempted to move their jaw or neck, making it more or less impossible to talk.

8 Lead sprinkler

Deceptively designed to look like a holy water sprinkler, this device was actually filled with molten lead, acid or boiling hot oil or water. The long handle was shaken to shower the victim's body with the substance inside. This caused horrific burns and was potentially lethal.



Miserable medicine

The medical practices that did more harm than good

Nowadays, when you're feeling unwell, you can visit a clean hospital and receive tried-and-tested treatments from a doctor with years of medical training. We often take this modern medicine for granted, but our ancestors throughout history were not quite so lucky when it came to health care. In medieval England for example, poor hygiene and filthy living conditions meant that disease was very common.

However, with little knowledge of the human anatomy, many illnesses were attributed to witchcraft, demons, the will of god or even the positions of celestial bodies. Trepanning, which involves drilling a hole into the skull, was prescribed to allow the disease-causing evil spirits trapped inside to escape. Others believed that diseases were caused by the fluids in the body becoming unbalanced, so bloodletting – draining the blood from a particular part of the body – was thought to restore that balance to normal levels.

The 'doctors' who carried out these procedures were usually monks, as they tended to have basic medical knowledge, or barbers or butchers who were simply picked for the task because they had the right tools for the job. The equipment used was very rarely sterilised as little was known about contamination, and procedures were carried out with no form of anaesthesia to numb the pain. It's no wonder that people would put off seeking treatment for as long as possible!

"Many illnesses were attributed to witchcraft"

Terrifying treatments

Horrifying medical instruments and procedures from the past

Trepanning

Used to treat:

Headaches, seizures, mental disorders

Trepanning is one of the oldest surgical practices in history, with evidence dating back to prehistoric times. It involves drilling a hole in the skull to relieve pressure.



Dental key

Used to treat:
Toothache

To remove a damaged tooth, the claw end of the dental key was clamped around it and then the entire device was turned like a key in a lock to lift it out of the gum.



Artificial leech

Used to treat:

Various infections and diseases

Used for bloodletting, a popular treatment for a wide range of medical conditions, this device mimicked the action of real leeches, with rotating blades that cut into the skin while a vacuum in the cylinder sucked out the blood.



Lithotome

Used to treat:

Bladder stones

With the patient still awake, the lithotome was inserted up the urethra and into the bladder to grip onto smaller bladder stones or cut up larger ones so they could be passed naturally.

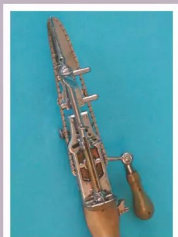


Osteotome

Used to treat:

Infections in the arms or legs

Rather than cutting down trees, this early chainsaw was actually used to amputate limbs. Unlike a hammer and chisel, the hand-cranked osteotome could cut through bone without causing it to splinter.



Weapons of war

The chemical arms race changed warfare forever

Chemical weapons

On 22 April 1915, Germany shocked the world by launching the first large-scale gas attack in war. After waiting several weeks for the wind to blow in the right direction, German soldiers released clouds of chlorine gas near the enemy trenches in Ypres, suffocating the unprepared Allied troops. Although The Hague Convention of 1899 prohibited the use of poisonous weapons, Germany justified its actions by claiming that France had already broken the ban by deploying tear gas grenades in 1914. The chlorine gas attack kick-started a chemical arms race, and by the end of World

War I around 50 different chemicals had been used on the battlefield. The most prevalent were chlorine, phosgene and mustard gas, which would result in slow and painful deaths if soldiers were exposed to large enough quantities. Eventually, gas masks were developed for protection, but chemicals such as mustard gas could still cause horrific blisters if they came into contact with the skin. Among the most devastating chemical weapons are nerve agents, such as sarin, which attack the nervous system. Even small concentrations can be lethal, killing in mere minutes.



Chlorine

Appearing as a pale green cloud with a strong bleach-like odour, chlorine gas reacts with water in the lungs to form hydrochloric acid. This damages the lung tissue, causing coughing, vomiting and eventually death.



Phosgene

This colourless gas with a musty odour reacts with proteins in the alveoli, tiny air sacs found in the lungs. This leads to fluid in the lungs and eventually suffocation, but the symptoms can take up to 48 hours to manifest.



Mustard gas

With the odour of garlic, horseradish or sulphur, yellow-brown clouds of mustard gas cause chemical burns on the skin, eyes and respiratory tract, leading to large blisters, temporary blindness and shortness of breath.



Sarin

Colourless, tasteless and odourless, this gas blocks normal communication between nerves. The nerve signals become stuck 'on', and muscles are unable to relax. This can lead to spasms, paralysis and asphyxiation.

The Geneva Protocol

By the end of World War I, over 125,000 tons of poison gas had been deployed in battle. Although it was only responsible for less than one per cent of the war's total fatalities, the psychological terror it had inflicted on soldiers was immense. On 17 June 1925, seven years after the war had ended, the Geneva Protocol was introduced, prohibiting the use of chemical and biological weapons. 138 states have now signed the treaty.

Napalm

Napalm is a flammable liquid with a gel-like consistency, allowing it to stick to surfaces easily. In a bomb, it is combined with gasoline or jet fuel to explode upon impact, burning at over 2,760 degrees Celsius. Contact with skin can result in severe burns and even death by asphyxiation. When ignited, napalm generates carbon monoxide and removes oxygen from the air, suffocating those in the vicinity. Some of the greatest atrocities of war were caused by napalm.

Greek fire

Developed by the Byzantine Greeks in the 7th century, Greek fire was a flammable liquid that could burn on water, making it particularly effective for naval warfare. It was sprayed at the enemy using early flamethrower devices, or thrown in primitive hand grenades. The resulting fire could only be extinguished with sand, vinegar or urine. The true ingredients are a mystery, but scientists believe it could have contained petroleum, sulphur and pine tar.



38 states originally signed the Geneva Protocol to ban the use of chemical weapons



Napalm fires combust oxygen in the air, turning carbon dioxide into carbon monoxide



Greek fire was the napalm of its day, but its ingredients are a mystery



Medieval writing equipment

Why we used quills for over 1,300 years

Before the invention of the pen, most people used quills to write with. These were stripped bird feathers, usually from geese. In particular, swan feathers were very sought after but geese, crow, owl and turkey feathers were simpler to obtain.

Quills were easy to supply, comfortable to hold and tapered down to a point so the writer could create all the subtle curves and lines of fine handwriting.

The first record of their use was around the 6th century by European monks, replacing the reeds they had been using up

until then. Feathers were stripped, buried in hot sand to harden, hollowed out and then filled with ink. They were time-consuming to make and had to be refilled and reshaped regularly, but continued to be the main writing implement until the metal pen became popular in the mid-19th century.

How to make a quill

Travel back through time to the Middle Ages and write with feathers



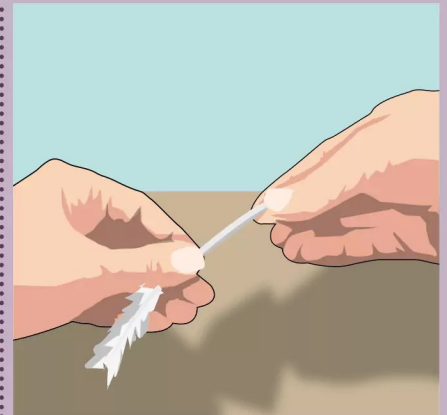
Prime your feather

Scout around near a river or lake for a feather that has been dropped by a swan or goose. Ideally it should be around 15cm long and intact. Using a Stanley knife, very carefully shave off the fluffy feathers at the pointy end. You should be able to grip the quill without touching any feathers. Then place the feather in a bowl of water and leave it overnight to soak.



Toughen and shape

Heat sand in the oven at 175°C and bury the feather, using oven gloves to avoid burns. Wait until the sand has cooled and remove the hardened feather. From about 2.5cm above the tip, slice down at an angle of around 45 degrees to the tip of the feather. Make a small, flat cut on the opposite side of the tip. There should now be two spikes on the tip that you need to pinch together.



Finishing off

Shave the pinched end so it is nice and smooth and you should have a feather tapering nicely to a point. Dip your quill in the ink where it should soak up the writing fluid. There should be enough to write a fair few lines, depending on how tightly you've pinched it together. The tighter you've pinched it, the more ink it should retain. Take it out and begin writing like a medieval scribe!

The first hearing aids

From 19th-century ear trumpets to microchips

Although they may look like something out of a cartoon, ear trumpets were used frequently throughout the early-19th century. The first type of hearing aid had a large surface area that amplified sound that was directed toward the ear. They were made of metal, silver, wood or animal horns and were incredibly bulky. However, as their use became more widespread, they featured a collapsible design so the ear trumpet could be carried in pockets and removed when necessary. Horns were so popular that even midwives would use a similar instrument to the ear trumpet for listening to pregnant ladies' wombs.

Early hearing aids could hardly be described as 'inconspicuous'





The metal rivets reinforce the stitching to make the garment last longer



Main image: Lumberjacks in Oregon, US, wearing Levi's jeans in 1880
Inset: An advert from 1874 targets the working class

Denim by the decades

'Rockabilly'
How have jean styles changed over the years?



The birth of blue jeans

The 'riveting' story of how two visionary immigrants created an American classic

Denim jeans are a fashion essential around the world, but their origins are much more humble. During the late 1800s, America was in the full throes of the Gold Rush, and Jacob Davis, a Latvian immigrant, was working as a tailor in Nevada. Jacob sold clothing to local miners and workmen, who required strong and hard-wearing material for their work. It was here that Jacob struck gold.

By fixing small copper rivets to the most strained areas of the garment, such as the pockets, he created a much more durable design. This new, robust clothing caught public attention and Jacob's 'waist overalls', as they were known, became so popular that he sought a patent to protect his idea. But a patent required money, so he asked his fabric supplier, Levi Strauss, for help.

Bavarian-born Strauss had also travelled to the States to seek his fortune and saw potential in Jacob's product. The pair were granted a patent in 1873 and before long the modern denim jean was being worn in factories, farms and mines across the country. Indigo was chosen to dye the jeans because it was dark enough to hide stains, it didn't penetrate the woven fabric and, crucially, it was cheap.

When the patent expired in 1908 dozens of imitations flooded the market and in the decades to come were worn by men and women of all classes. Teenagers began calling them 'jeans' instead of 'overalls' and manufacturers officially adopted the term in the 1960s. Today their popularity is as durable as the original riveted design.

5 jean-ius facts

Denim jeans is a misnomer

In the late 1700s, two cotton fabrics were produced: denim and jean. Denim, originally made in de Nîmes, France, was more durable and thicker than jean, used to make workers' trousers in Genoa, Italy.

They were almost banned

Jeans gained a 'bad boy' image after featuring in movies like *Rebel Without A Cause*. Schools began banning them, so Levi's ran a campaign starring a clean-cut, denim-clad kid with the slogan 'Right for school'.

Levi wasn't his real name

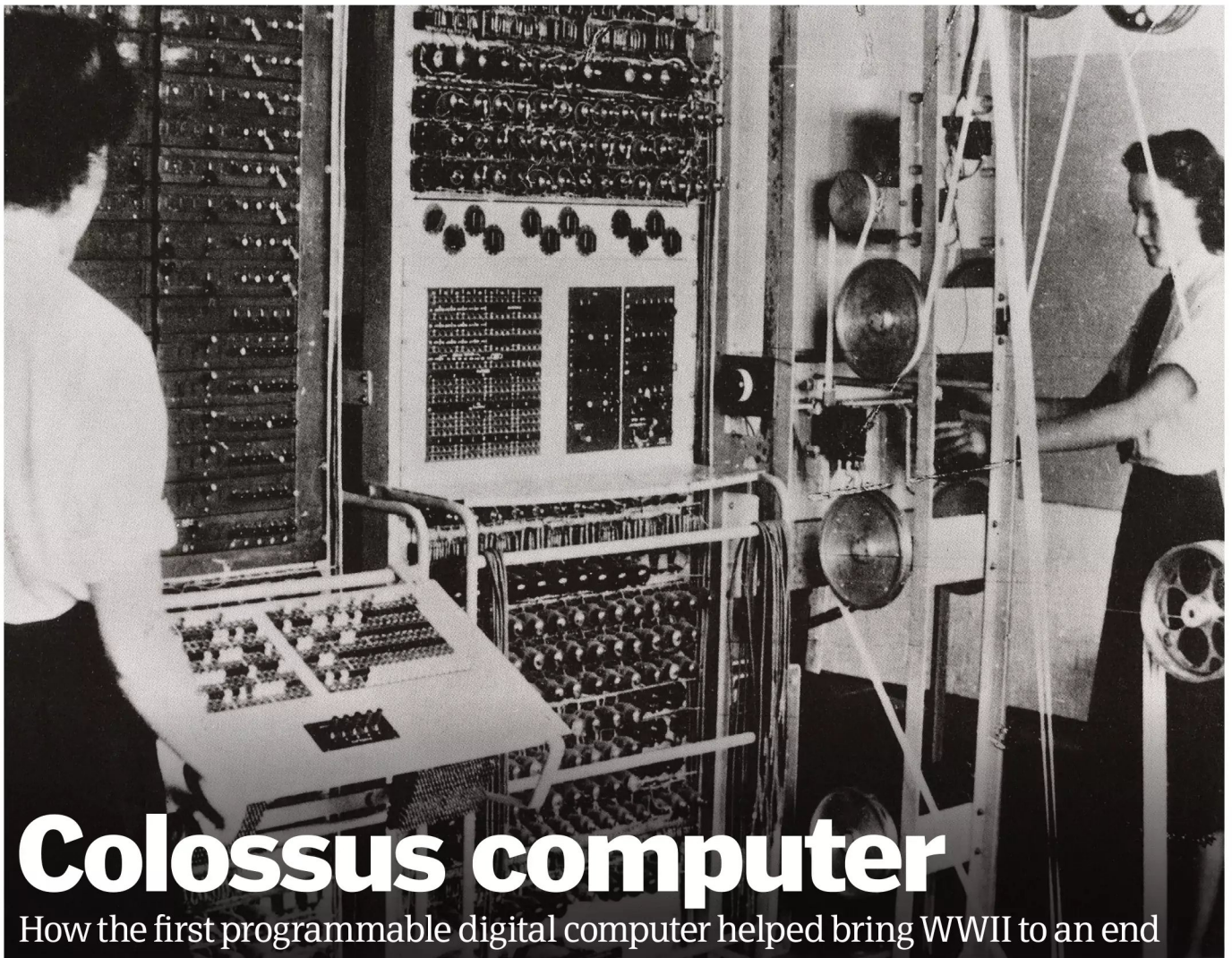
He was born Loeb Strauss, but like his future business partner, Jacob Davis, he changed his name after immigrating to the US. Eventually Levi set up a wholesale dry goods business in San Francisco.

Duck or denim?

When Levi and Jacob began mass-producing their waist overalls, they manufactured two kinds. One was from blue denim and the other from brown cotton duck — a tough canvas material that was used to cover wagons.

Built to last

In the Levi Strauss & Co archives lies two pairs of jeans dating from the late 1870s or early 1880s, which are thought to be the oldest in existence. Only two people know the combination to the fireproof safe that protects them.



Colossus computer

How the first programmable digital computer helped bring WWII to an end

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and the keystream established.

Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A colossal reconstruction

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after WWII, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus's optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.



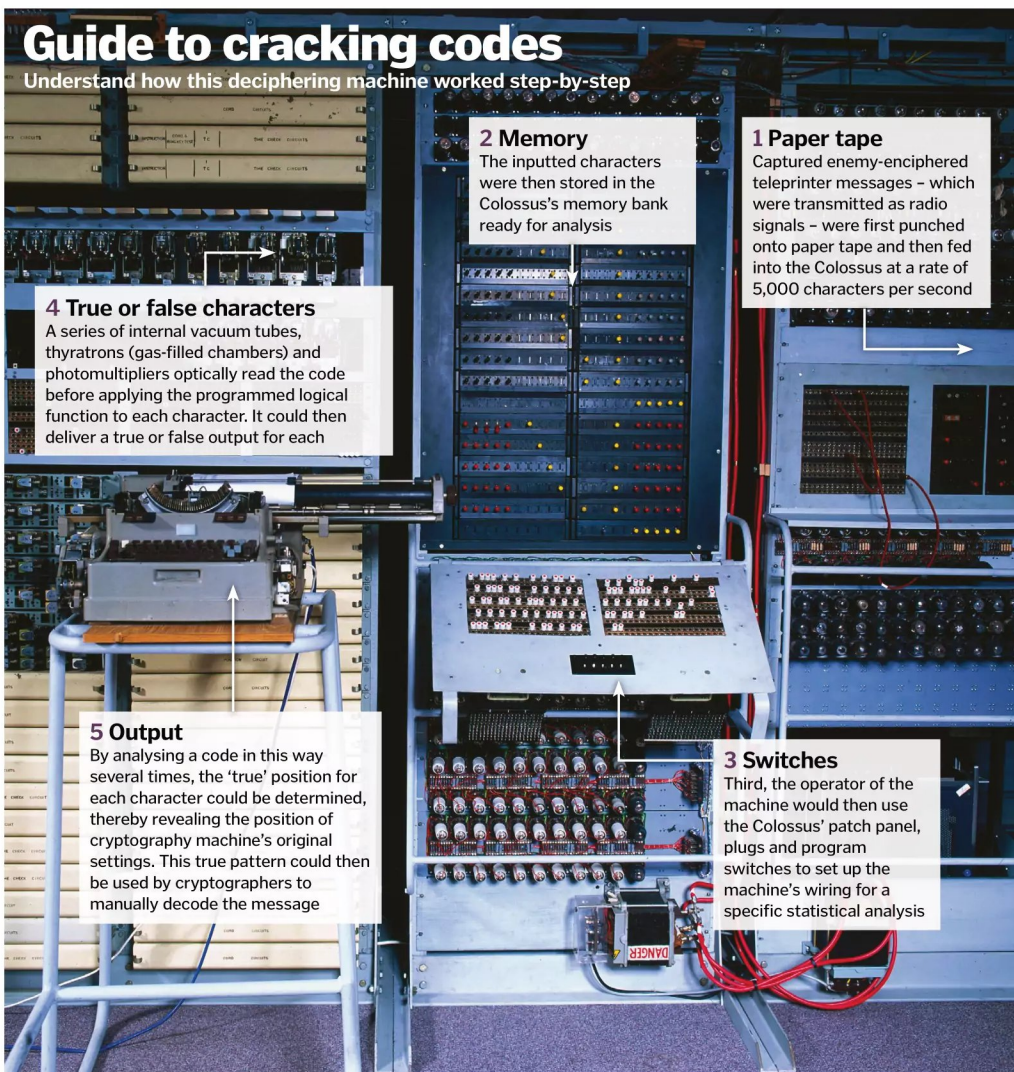
A sculpture to commemorate Flowers, with his son (left)

Flowers in focus

Thomas (Tommy) Flowers was the British engineer behind the revolutionary design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades after the war as he was sworn to secrecy.



Guide to cracking codes

Understand how this deciphering machine worked step-by-step

2 Memory

The inputted characters were then stored in the Colossus's memory bank ready for analysis

1 Paper tape

Captured enemy-enciphered teleprinter messages – which were transmitted as radio signals – were first punched onto paper tape and then fed into the Colossus at a rate of 5,000 characters per second

4 True or false characters

A series of internal vacuum tubes, thyatrons (gas-filled chambers) and photomultipliers optically read the code before applying the programmed logical function to each character. It could then deliver a true or false output for each

5 Output

By analysing a code in this way several times, the 'true' position for each character could be determined, thereby revealing the position of cryptography machine's original settings. This true pattern could then be used by cryptographers to manually decode the message

3 Switches

Third, the operator of the machine would then use the Colossus' patch panel, plugs and program switches to set up the machine's wiring for a specific statistical analysis



In 1993 Bletchley Park was re-opened as a museum devoted to code breakers

Bletchley's role in WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes, Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communications.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes – as discussed in more detail in 'A colossal reconstruction' opposite.



After WWII Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

"Bletchley Park was the main decryption headquarters throughout World War II"



Rack-and-pinion railways

How did these unique transit systems help hefty locomotives scale steeper mountain slopes than ever before?

A rack-and-pinion railway (also known as a cog railway) was one that employed a toothed track. The addition of the toothed rail – which was usually located centrally between the two running rails – enabled locomotives to traverse steep gradients over 7 per cent, which remains to this day the maximum limit for standard adhesion-based railways.

Core to the operation of each rack-and-pinion system was the engagement of the locomotive's circular gears onto the linear rack. The rack and pinion therefore was essentially a means of converting the rotational energy generated by the train's powerplant into linear motion on the rack. As both the rack-and-pinion gears had teeth, the system also acted as an additional form of adhesion to the track, with the inter-meshing teeth holding the vehicle in place when not in motion.

Due to the primary form of power traditionally being steam, for rack-and-pinion systems to work the trains needed to be considerably adjusted. This modification stretched from the undercarriage of the train (so pinions could be installed) to the tilting of its boiler, cab and superstructure.

Tilting was necessary as steam engine boilers require water to cover the boiler tubes and firebox at all times to maintain stability – something that is nigh-on impossible to achieve if the train isn't level. As such, cog railway locomotives would lean in towards the track to counter the terrain's gradient.

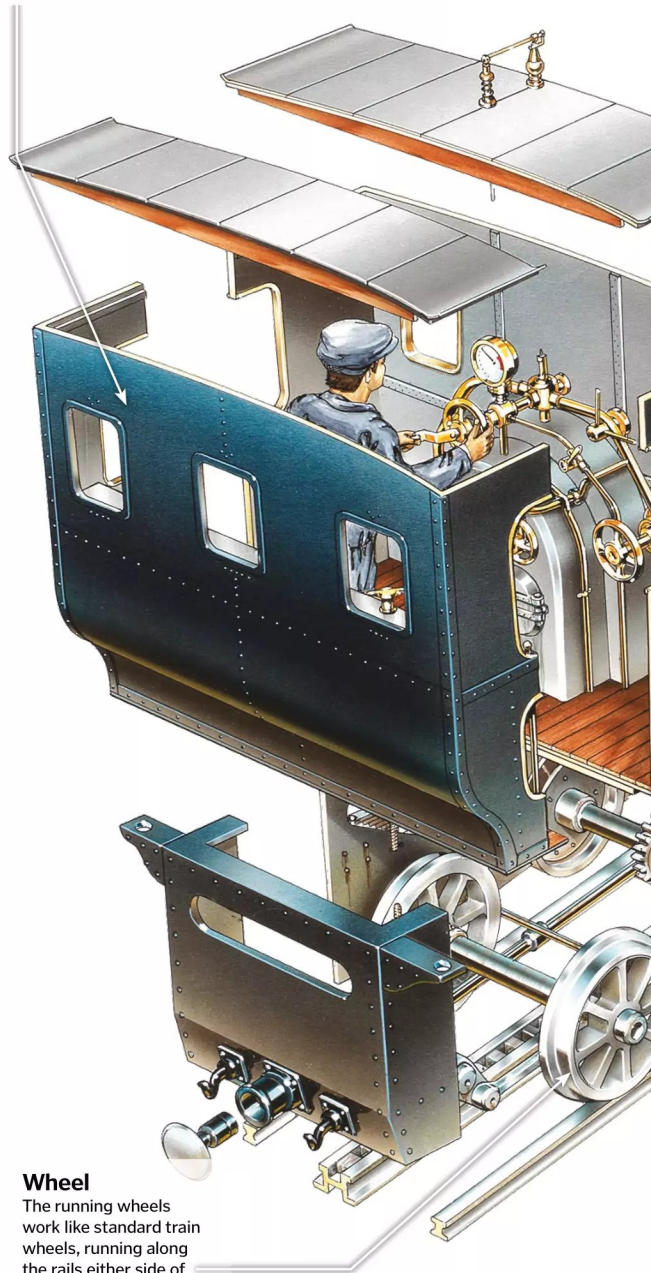
Today, while rare, rack-and-pinion systems are still in operation worldwide, albeit with a mix of steam engines and diesel/electric locomotives. One of the most famous is the Mount Washington Cog Railway, which we look at more closely in the boxout opposite.

Rack and roll

Understand the anatomy of a rack-and-pinion locomotive now with our cutaway illustration

Cabin

To the rear of the engine and carriage is the cabin. From here the driver controls the steam boiler and the engagement of the pinion gears



Wheel

The running wheels work like standard train wheels, running along the rails either side of the central rack



A rack-and-pinion railway built with a Strub system in rural Italy, 1920

Engine

Older cog railways would use steam engines to provide the power to drive the pinion gears. As with the cab, the engine is tilted forward so it's level during operation

Buffer

Unlike standard adhesion trains, rack-and-pinion systems don't tend to attach the carriage to the locomotive with a linkage. Instead, the carriage is simply pushed with the locomotive's buffers

Carriage

Passengers sit in a covered wooden carriage. Due to the slow nature of the system, larger-than-standard windows are often installed that offer panoramic views

Rail

Either side of the rack are two standard rails for the carriage and locomotive's wheels to run on. These allow for the switching of lines and access to mechanical turntables for 360-degree rotation

Rack

In the centre of the line is the rack, a toothed rail into which the locomotive's pinions slide. This engagement between the pinion and the rack allows the train to maintain a good grip even on steep terrain

Pinion gears

Mounted to the locomotive's undercarriage is a series of circular, toothed gears. As these rotate, driven by the engine, the teeth slot into the recesses in the rack, helping haul the train along.

Cog railway evolution

1 Marsh

Made famous by the Mount Washington Cog Railway, the Marsh system – invented by Sylvester Marsh in 1861 – used the locomotive's gear teeth like rollers, arranged in rungs between two 'L'-shaped wrought-iron rails.

2 Rigenbach

The 1863-made system created by inventor Niklaus Rigenbach used a ladder rack made from steel plates connected by regularly spaced rods. While effective, the fixed ladder rack was fairly complicated and expensive to build, so very few examples survive.

3 Abt

Carl Roman Abt improved the Rigenbach system in 1882 by using multiple solid bars with vertical teeth machined into them that were mounted centrally between the rails. This ensured the pinions on the wheels were in constant contact with the rack.

4 Locher

Eduard Locher's system designed in 1889 had gear teeth cut into the sides of the rails rather than the top, which were engaged by two cog wheels on the locomotive. This new system could work on steeper track gradients than anything prior.

5 Strub

Invented by Emil Strub in 1896, the Strub system utilised a rolled flat-bottom rail with rack teeth machined into the head 100mm (4in) apart. The safety jaws installed on the locomotive gripped the underside of the head in order to prevent dangerous derailments.

A mechanical mountain climber

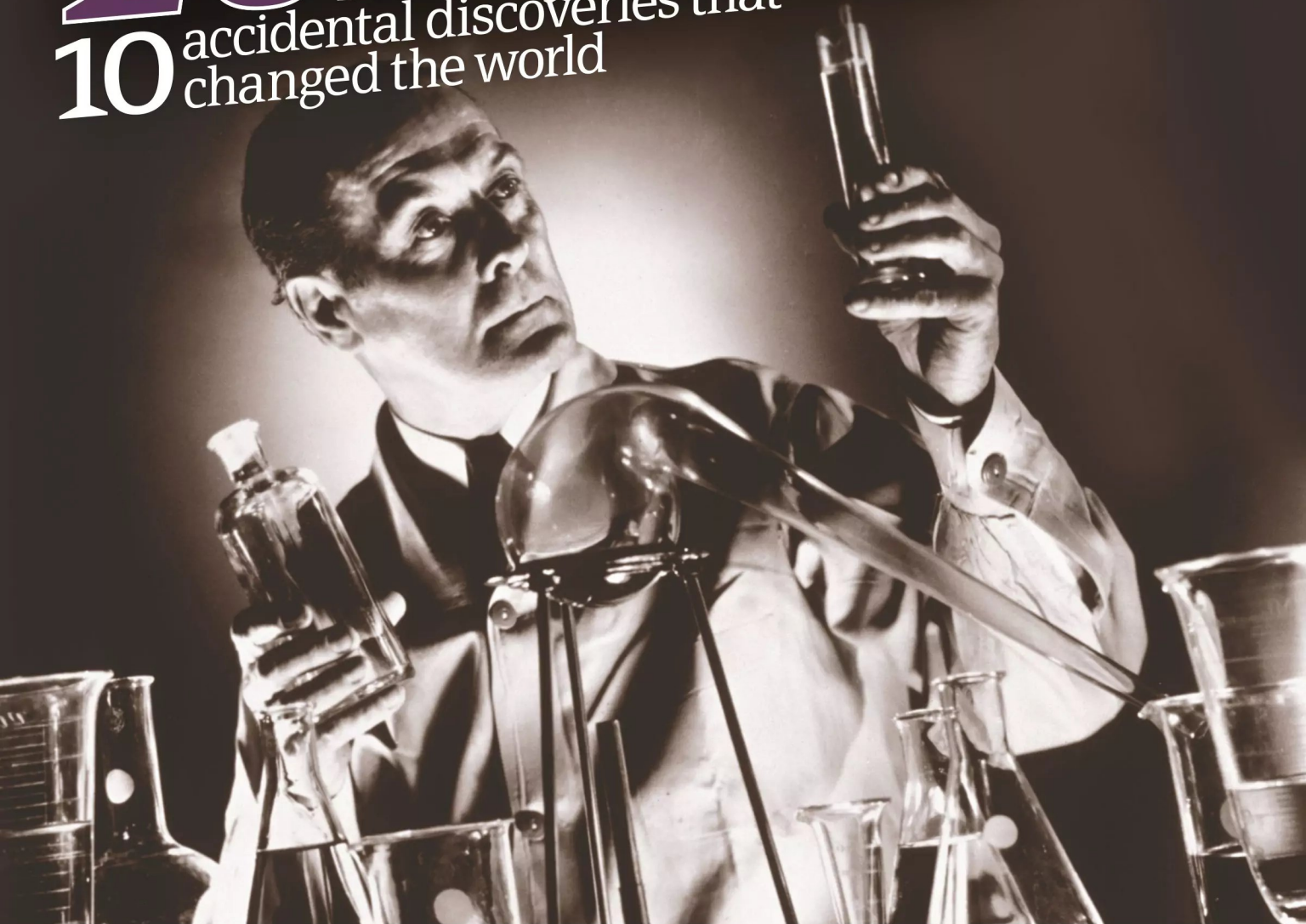
The Mount Washington Cog Railway in New Hampshire, US, was the first rack-and-pinion railway used to climb a mountain. Completed by Sylvester Marsh in 1869, the system is the second-steepest rack railway in the world, with a top gradient of 37.4 per cent. The railway runs 4.8 kilometres up Mount Washington's western slope, beginning at 820 metres above sea level and culminating just short of the peak at 1,917 metres. The locomotive goes up at 4.5 kilometres per hour and descends at 7.4 kilometres per hour. Despite being built 144 years ago, this cog railway is still fully operational.





EUREKA!

10 accidental discoveries that changed the world



It's no secret that the best ideas often come to us when we least expect them to. For some it may be on the drive home from work or in the middle of the night, while others may have their lightbulb moments while taking 'time out' in the bathroom. The ancient Greek mathematician Archimedes was in the latter group, having famously realised how to measure the volume of irregular objects while taking a bath. When he climbed in, the water level rose, and it occurred to him that the volume of water displaced must be equal to his own. How he maintained his reputation after

running naked through the streets screaming 'Eureka', we're not sure!

It's not just ideas that can come to us by chance; sometimes it's a physical invention. While it's true that most of history's greatest discoveries were made after years of painstaking research, others happened completely by accident. Take the humble ice lolly, for example. Arguably a lifesaving invention during the hot summer months, it was initially the result of a failed attempt at making soda. In 1905, an 11-year-old boy called Frank Epperson had been trying to make

himself a sugary beverage, but left his concoction outside overnight with the stirrer still in the cup. Being the middle of winter, the liquid froze, and in the morning Frank enjoyed a frozen treat on a stick. Eighteen years later, he realised the commercial possibilities his accidental invention could have, and he began selling them on California beaches.

So whether it's the result of a clumsy spill or a contaminated laboratory, accidental inventions are just a slapdash scientist away, as long as they are able to realise the potential. Naked celebrations are, of course, optional.

Penicillin

1 A contaminated experiment is any scientist's worst nightmare, but in the case of biologist Alexander Fleming, it would be his making. While studying the influenza virus, he accidentally left a petri dish out of the incubator while he was away on holiday. Upon returning, he discovered that the petri dish, in which he had been growing staphylococcus bacteria, had also begun to grow mould. When Fleming examined the dishes more closely he noticed that there was a ring around the mould where the bacteria had not grown. The 'mould juice' was actually penicillin, produced by the *Penicillium* mould that had contaminated the dish. Fleming later found that it was able to kill many different types of bacteria. It was two other scientists, Howard Florey and Ernst Chain, who turned penicillin into a drug, but without Fleming, antibiotics may never have been invented.

DISCOVERER CASE FILE

Sir Alexander Fleming

Born in Scotland in 1881, Fleming went on to study at St Mary's Hospital, London, where he completed a bachelor's degree in medicine. His accidental discovery of penicillin earned him a Nobel Prize, which he shared with Florey and Chain.

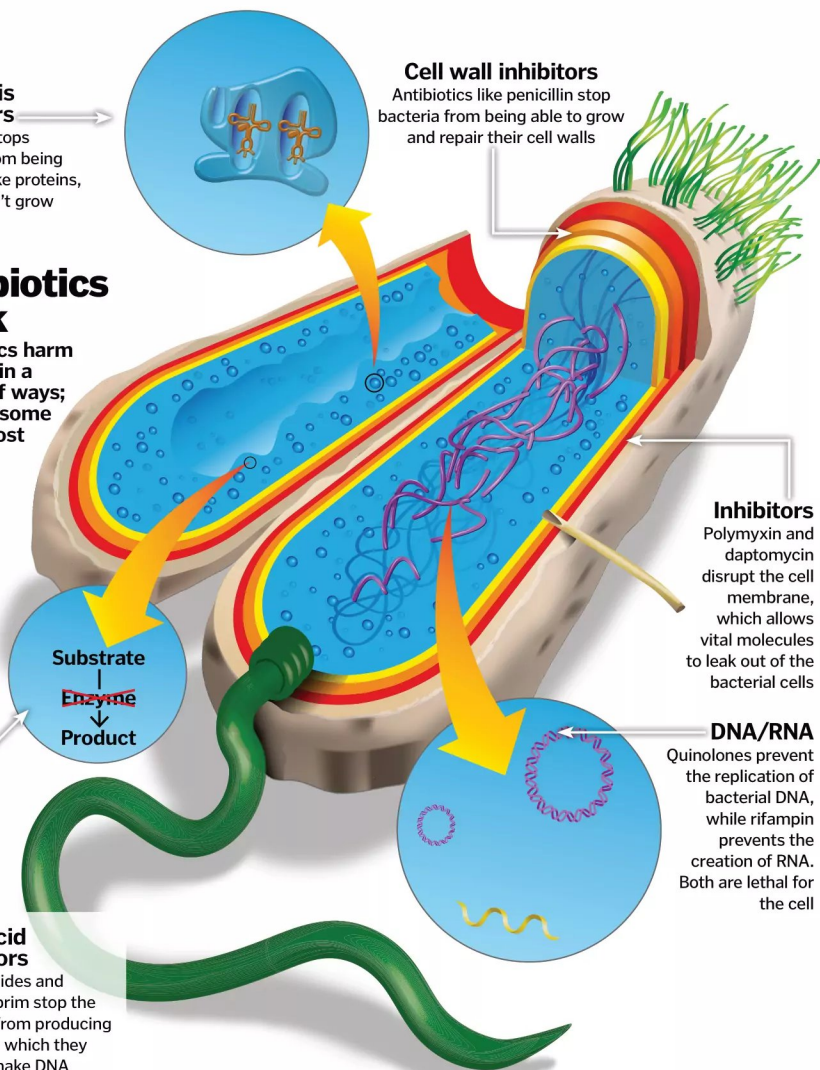


Protein synthesis inhibitors

This type stops bacteria from being able to make proteins, so they can't grow

How antibiotics work

Antibiotics harm bacteria in a variety of ways; here are some of the most common



Plastics (Bakelite)

2 Throughout the 19th century, scientists tried desperately to solve the mystery of polymers – very large molecules that can be expanded and moulded. In 1870 an American inventor modified a naturally occurring polymer called cellulose to create an incredible new material called celluloid, which could be moulded or rolled when heated. But it would be another 40 years before the first wholly synthetic plastic was made. The discoverer, Leo Baekeland, had been experimenting with synthetic resins. After heating the liquid, he found that it produced a solidified matter, which was insoluble in solvents and did not soften when heated. He called it 'Bakelite', and it was soon used in the production of everything from electricals to jewellery.

DISCOVERER CASE FILE

Leo Baekeland

A Belgian chemist born in 1863, Baekeland left his homeland for New York aged 23. Here he invented Velox photographic paper, which allowed developments under artificial light, before turning to plastics.



Bakelite was used to make telephone casings because it was electrically nonconductive and heat-resistant



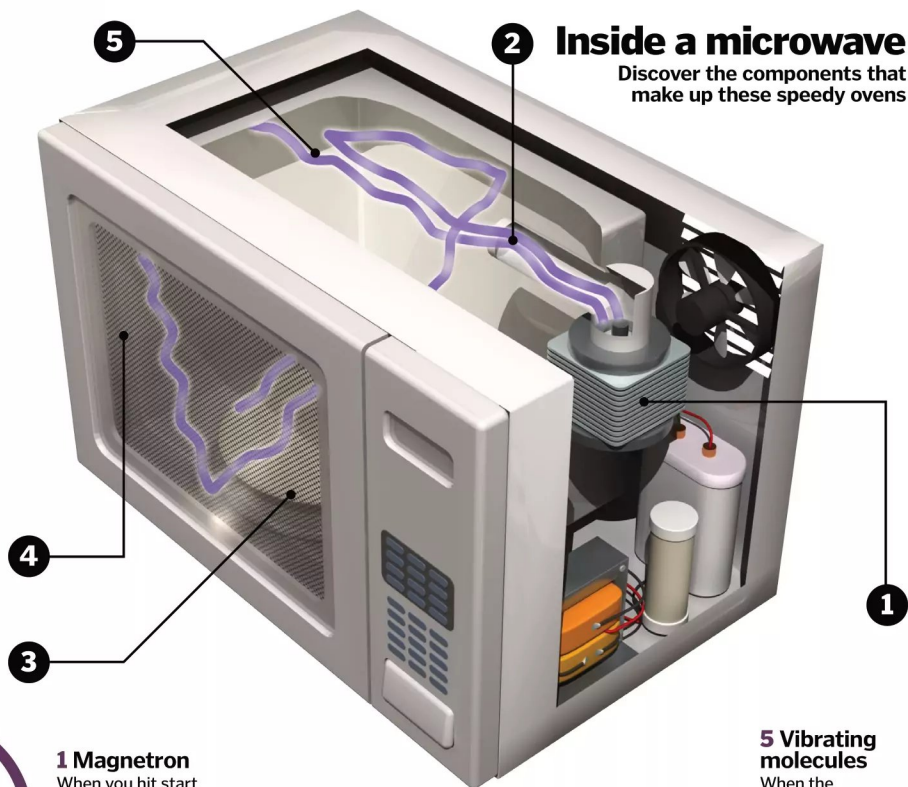
Microwave

3 Not only was the microwave discovered by accident, it was also discovered by a man who had not even completed high school. At the age of 12, Percy Spencer left education to work in a spool mill and was later hired to install electricity in a nearby paper mill. In the 1920s, Spencer began working as an engineer for Raytheon, a company that went on to improve radar technology for Allied forces in World War II. One day, he was stood in front of an active radar magnetron when he noticed the chocolate bar in his pocket had melted. He began testing the effects of magnetrons on other foods, and invented the first true microwave oven by attaching a high-density electromagnetic field generator to an enclosed metal box. The oven was a success, and in 1945 the company filed a patent for the first commercial microwave.

DISCOVERER CASE FILE

Percy Spencer

Born in 1893, at eighteen months old Spencer's father died and his mother left him in the care of his aunt and uncle. Despite his difficult start, he would become one of the world's most famed physicists.



Inside a microwave

Discover the components that make up these speedy ovens

1 Magnetron

When you hit start on a microwave, the magnetron takes electricity from the power outlet and converts it into high energy microwaves

2 Wave guide

These waves are blasted into the food compartment through a channel called a wave guide

3 Turntable

The food spins around on a turntable, allowing it to be cooked evenly

4 Metal walls

The microwaves bounce off the reflective metal walls to hit the food from different angles

5 Vibrating molecules

When the microwaves penetrate the food, they cause the molecules inside it to vibrate faster. This quickly heats the food up

Artificial sweetener

4 The first artificial sweetener, saccharin, was discovered by a Russian chemist called Constantin Fahlberg. He had been experimenting with preservatives in his work, and while eating a bread roll, he noticed that it had been sweetened by the substance left on his hands. He went back to the lab and retraced his steps, until he was able to synthesise the sweetener in bulk.



DISCOVERER CASE FILE Constantin Fahlberg

Fahlberg was initially hired to analyse the purity of sugar.



Saccharin rose to popularity during World War II, when sugar became scarce



Superglue

5 This super-sticky substance was discovered by accident – twice! Chemist Harry Coover had been attempting to make clear plastic gun sights for the Second World War, and one formulation he tested produced an extremely quick bonding adhesive. It was useless for his gun sights, though, and he forgot about it until almost ten years later, when he stumbled across it again while developing heat-resistant canopies for jet airplanes. This time he realised its potential, and the product was put on the market.



DISCOVERER CASE FILE Harry Coover

Coover worked as a chemist for Eastman Kodak.



Coca-Cola

6 After being wounded in the American Civil War, pharmacist John Pemberton became addicted to morphine. Seeking an alternative, in 1886 he began experimenting with coca – the plant from which cocaine is derived. He eventually stirred up a fragrant, caramel-coloured liquid that he combined with carbonated water and put on sale for five cents a glass. The soda, named Coca-Cola, would become the world's fourth most valuable brand.



DISCOVERER CASE FILE John Pemberton

Pemberton established a wholesale drug business.

Stainless steel

7 Steel has been forged for millennia, but it wasn't until 1913 that a metallurgist called Harry Brearley discovered a way to stop it rusting. He had been tasked with finding an erosion-resistant metal to prolong the life of gun barrels. Legend has it that as attempt after attempt failed, his pile of scrap metal grew bigger, and he later noticed that one of the scraps hadn't rusted like the others. He had invented stainless steel, and quickly saw its potential in the cutlery industry.



DISCOVERER CASE FILE Harry Brearley

Brearley was lead researcher at Brown Firth in 1908.

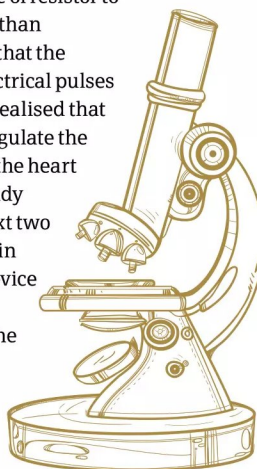


The pinnacle of New York's Chrysler Building is clad with non-rusting stainless steel

Pacemaker

8 Pacemakers have existed in a very rudimentary form since the 19th century, when it was discovered that electrical impulses could be used to provoke a heartbeat. However, the devices that followed were large and bulky and had to be plugged into a mains current, putting the patient at risk of electrocution. It wasn't until 1960 that battery-powered

implantable pacemakers came into use, having been invented four years previously. Electrical engineer Wilson Greatbatch was working on a heart-rhythm recorder when he added the wrong size of resistor to the circuitry. Rather than recording, he found that the device produced electrical pulses instead. He quickly realised that it could be used to regulate the electrical activity of the heart and guarantee a steady rhythm. Over the next two years, he succeeded in miniaturising the device and making it safe from bodily fluids. The first patient, a 77-year-old man, went on to live for a further 18 months.



DISCOVERER CASE FILE

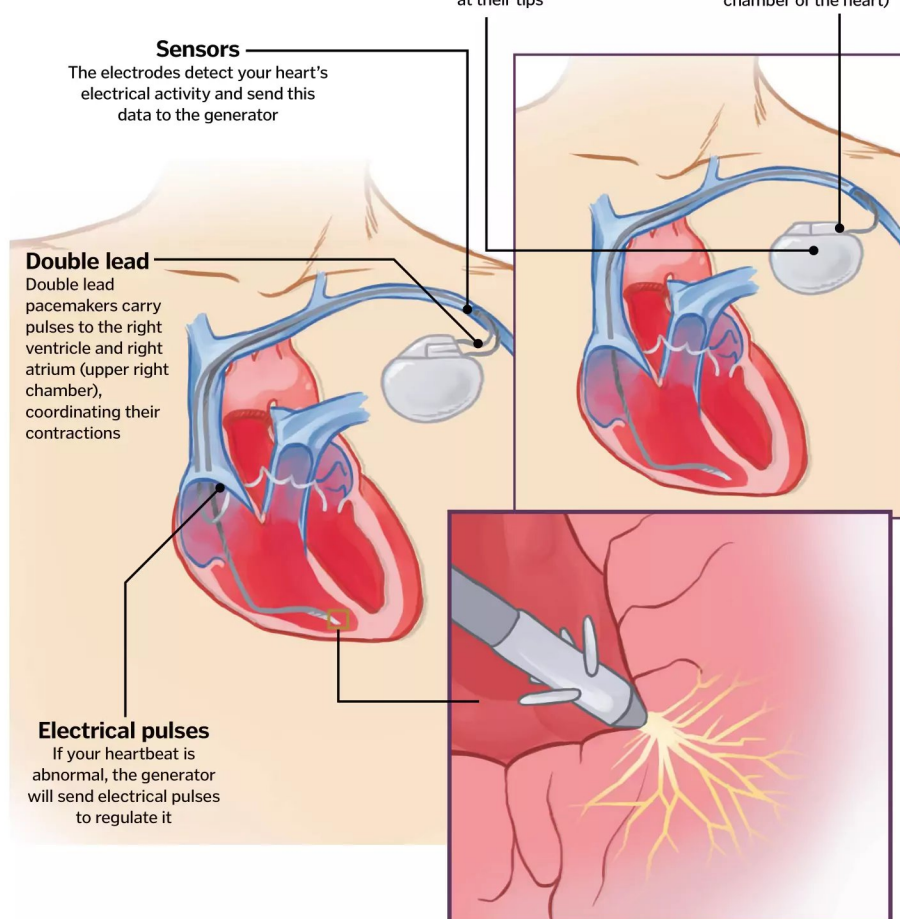
Wilson Greatbatch

The American engineer and inventor was born in New York in 1919, and served in World War II before completing a degree in electrical engineering. By the time of his death in 2011, he held over 325 patents.



How a pacemaker works

Discover how these amazing pieces of tech can keep our hearts beating



Teflon

9 The non-stick substance found on frying pans was inadvertently invented by a man called Dr Roy Plunkett. He had been trying to synthesise a non-toxic alternative to refrigerants like sulphur dioxide and ammonia, and was experimenting with tetrafluoroethylene (TFE). After storing the gas in cylinders, he opened one to discover that it had polymerised into a waxy white powder that was extremely sticky and had a very high melting point. Three years later, the substance, which was named Teflon, was patented.



DISCOVERER CASE FILE

Roy Plunkett

Plunkett received the John Scott Medal for the "comfort of humankind".

Protecting a pan

Peel back the layers to find out what makes modern frying pans so practical

Topcoat

This prevents food from sticking to the pan, for easy release and clean-up



Primer

The rugged primer makes the pan more abrasion resistant and enhances its durability

Midcoat

A tough midcoat provides resistance to scratches and abrasions

Base

The hard base is usually made from aluminium or stainless steel

X-Rays

10 It was while German physicist Wilhelm Röntgen was investigating the effects of cathode ray tubes that he made a curious discovery. During an 1895 experiment, he evacuated the tube of all air and filled it with gas before passing an electric current through it. Despite it being covered with black paper, he noticed that a screen several feet away was illuminated by the invisible rays, which he named 'X' to indicate the unknown. They were later found to pass through human tissue, allowing for the imaging of bones.

DISCOVERER CASE FILE



Wilhelm Röntgen

Born the only child of a cloth merchant in 1845, Röntgen studied mechanical engineering.

Röntgen took this radiograph of his wife's left hand





The Antikythera mechanism

An ancient scientific device that accurately calculated the locations of stars and planets

The Antikythera mechanism was the most advanced astronomical instrument of the ancient period. Assembled by the ancient Greeks, or perhaps the Babylonians, it was lost for 2,000 years before being discovered among artefacts taken from a shipwreck off the Greek island of Antikythera in 1901.

After meticulous study, scientists and historians declared the distorted mass of bronze to be an analogue computer, able to determine the positions of planets and the timing of eclipses. It accurately displays the phases of the Moon as well as the location of the five known planets in antiquity (Mercury, Venus, Mars, Jupiter and Saturn) in the sky.

Initially contained in a wooden case, only around 40 per cent of the original remains survive, and it is too delicate to examine by hand, so X-ray imaging and CT scans have been used to reveal how it worked. Inside, interlinking bronze gears are precisely arranged and cut exactly to size to turn rotating dials and pointers. The mechanism is evidence of the Greek's impressive astronomical knowledge and dates back to 205 BCE, the earliest date listed in the inscriptions on the device. It's the first invention we know of designed to show the layout of all the known celestial bodies in the sky at any given time, and was likely used for both educational and scientific purposes.



The 82 remaining fragments are kept at the National Archaeological Museum in Athens, Greece

How it could have worked

Based on the gears discovered, scientists can predict the mechanism's inner workings

Precision

The larger dial on the front of the mechanism showed the days of the year. By rotating the handle powering the mechanism, the location of the Sun and Moon on any particular day could be learned, revealing when eclipses would occur

Primary gear

The device was kick-started by the primary gear, which turned the rest of the gears. One complete rotation equals the passing of a year

Olympiad cycle

On the back of the device, the metonic dial could indicate the times of the Panhellenic, Olympic, Nemean, Isthmian and Pythian Games

Metonic gear train

This section was used to calculate the month in the ancient Metonic system (which followed a 235-lunar-month cycle) and display them on a dial on the back of the mechanism

Lunar gear train

This section was used to calculate lunar phases and depict them on a dial on the front of the mechanism

Eclipse gear train

The lunar gear train calculated the month in the Saros cycle, a 223-lunar-month period between recurring eclipses

Saros lunar eclipse dial

Inscriptions here could be used to predict solar and lunar eclipses

Inscriptions

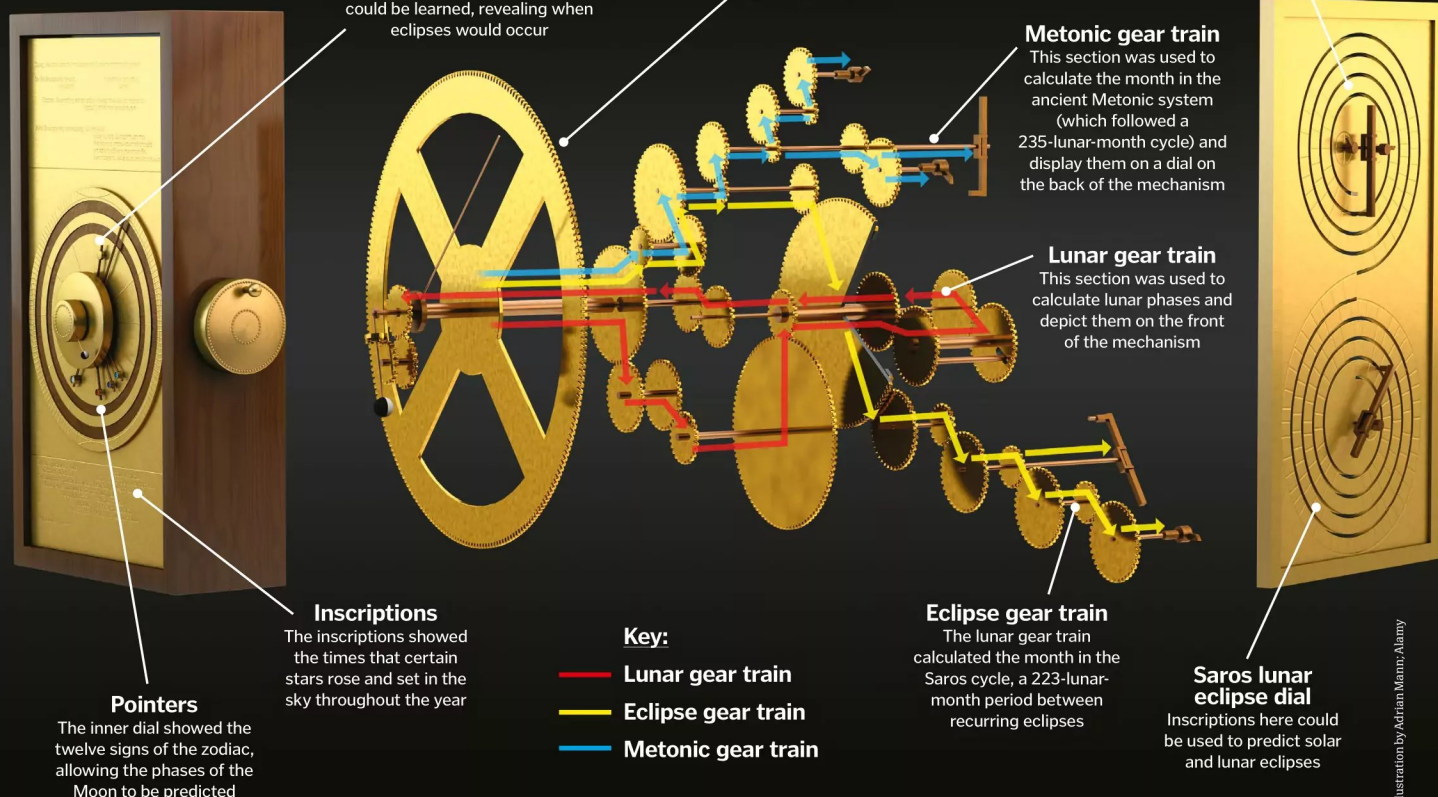
The inscriptions showed the times that certain stars rose and set in the sky throughout the year

Pointers

The inner dial showed the twelve signs of the zodiac, allowing the phases of the Moon to be predicted

Key:

- Lunar gear train
- Eclipse gear train
- Metonic gear train

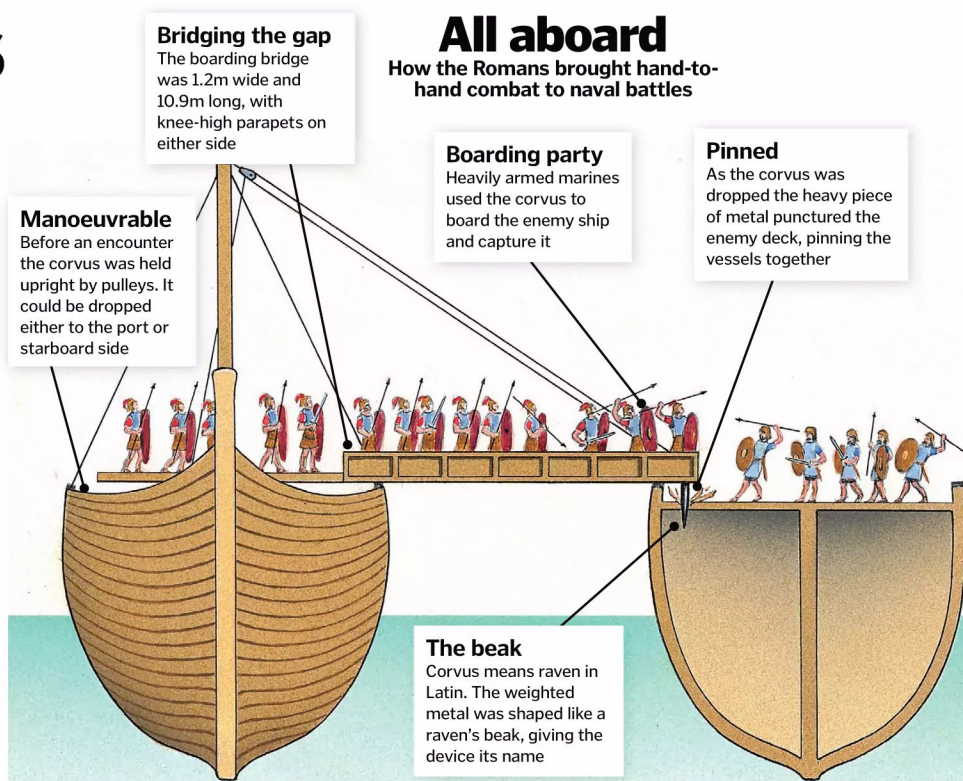


The corvus

The invention that turned the tide for the Romans during their first war at sea

As the Carthaginians approached the Roman fleet near Mylae in 260 BCE, they saw an unfamiliar object affixed to the prow of the opposing ships. The marines were startled, but as their ships were both faster and better constructed they continued their advance full of confidence. What followed would be remembered as a great victory for the Romans and a disaster for their adversaries.

A common tactic in ancient naval warfare was ramming and sinking enemy ships, but the Romans knew they were outclassed in a typical sea battle. Instead, they favoured boarding the enemy ships with their superior soldiers, and so they designed the corvus. They put the new invention into practice at Mylae. When their opponent's vessel neared they dropped their new boarding bridge onto their decks, pinning them and enabling Roman marines to swarm aboard and take the enemy ship.

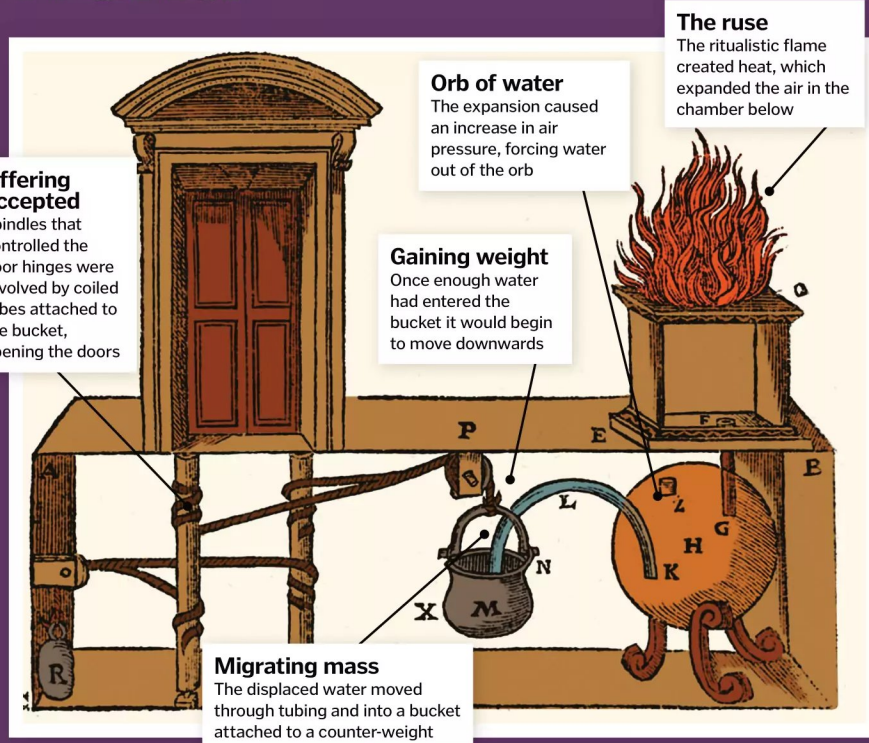


Automatic doors of the ancient world

A bright spark called Hero of Alexandria designed the world's first self-opening temple doors

As worshippers gathered around a temple of the ancient world they were treated to a sight so spectacular that it appeared to prove the existence of the gods. The congregation would watch as a temple priest stood beside a set of grand entrance doors and lit a large fire to begin his ritual. He would then make an offering over the flames, and after some time the doors would open wide, seemingly by the gods themselves.

But what looked to the crowd as divine intervention was in fact an advanced mechanism working beneath the temple's surface. It had been designed by Hero of Alexandria, a famous inventor whose knowledge of physics far exceeded that of his contemporaries. Hero understood that air could be pushed and pulled, and it was by exploiting this knowledge that he designed one of the greatest illusions of power in the ancient world.





PREHISTORIC PAINTING

How these ancient artworks provide a rare insight into the lives of Palaeolithic humans

Prehistoric cave paintings are believed to be among the first examples of human art. The remnants of images found in caves today provide archaeologists with a fascinating insight into the world of our Stone Age ancestors.

So how did they make the paint? Black paints could be made from a simple mixture of charcoal and a binder, such as saliva or animal fat. The earliest coloured paints were made from naturally occurring minerals (known as pigments) such as iron oxides, which were ground into a powder before being mixed with a binder. These pigments were in high demand, and some prehistoric artists may have travelled 40 kilometres or more to gather them.

To make a typical cave painting, an outline was scored on the wall with a sharp stone, then marked out with charcoal. The image could

then be filled in with a coloured pigment paint, and shaded to make it three-dimensional.

The majority of cave paintings are illustrations of animals that roamed the land nearby, including lions, rhinos, bears and even sabre-toothed cats. Images of the humans themselves are much less common. One theory for this is that it was believed that the artwork was a link to a spirit world, and the depictions would increase luck when hunting. Campfires in the caves helped to give the impression that the painted creatures were alive, with the illustrations dancing on the walls. Outlines of human hands, also known as hand stencils, are a common sight among cave paintings, thought to be a sort of artist's signature.

Scientists can estimate when a cave painting was made using radiometric dating, either using the rate of decay of the isotope carbon-14

in the pigments, or the rate of uranium decay in the surrounding rocks. Some paintings in Europe are thought to date back as far back as the Upper Paleolithic period, making them up to 40,000 years old. The European examples are perhaps the most well-known, but prehistoric cave art has also been found in Africa, Asia and Australia, with (relatively) more recent examples in the Americas dating back nearly 10,000 years. Based on the discoveries so far, cave art seems to have become less popular as warmer climates allowed humans to begin settling outside of caves.

Discoveries of prehistoric art continue to fascinate us today and provide a unique insight into the culture of our distant ancestors.



The prehistoric palette

The colours and shades used to illustrate the Stone Age world

In archeological terms, cave art is also known as 'parietal art'



Ochre

Ochre pigments can come in shades from red to yellow to brown, depending on their mineral blend, but they all contain iron oxide. Its texture allows it to be easily mixed with other pigments

Kaolin

Kaolin is a white-coloured clay and one of the Earth's most abundant minerals. Its name originates from the town of Gaoling in China, which is renowned for having rich kaolin deposits

Manganese oxides

One of the darkest colours used, manganese oxide could create shades that were brown, grey or black. Manganese deposits weren't common in caves adorned with artwork, so it's assumed painters would trek long distances to find a source

Carbon black

Monochrome paintings were a simple mix of carbon black and a binder. The colour was made from burning wood or plants, which created charcoal. It was often used as a ground layer for a polychrome image

Umber

Umber is another combination of iron and manganese that is darker than both sienna and ochre. The shade of its reddish-brown colour is dependent on which mineral was dominant in the mix. It could be heated to the even darker colour of burnt umber

Sienna

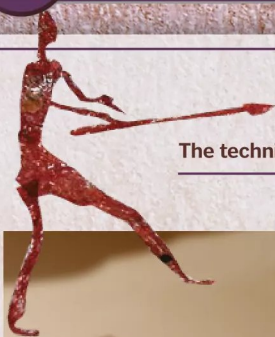
A mixture of iron oxide and manganese oxide, raw sienna is a pigment with a yellow-brown colour. When heated, it turned into burnt sienna, which is darker in tone and redder in colour

Green and blue

Cave art typically features red, brown, yellow and black, but none of the paintings, it seems, included blue or green. This can be explained in part by the lack of natural pigment sources for these shades. In the Palaeolithic period, obtainable blue-coloured minerals were rare, especially in Europe. Blue was used in later eras by the ancient Egyptians, who used powdered azurite to make blue-coloured jewellery. The omission of green shades is more difficult to comprehend, as green coloured minerals like malachite and terre-verte were abundant. One of the reasons given for the lack of green colour is that it may have simply not shown up as well as red or brown does under fire or torchlight.

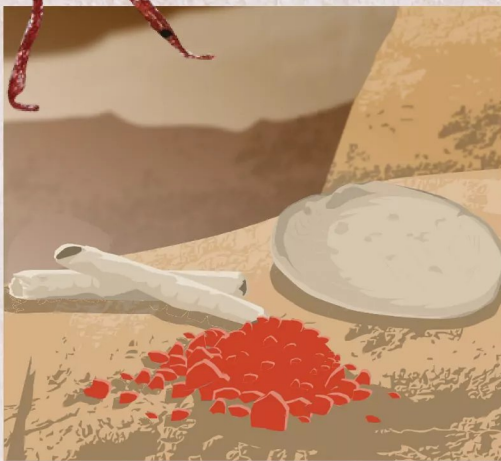
Clay ochre could be red, yellow or brown, but not blue or green





Hand stencils

The techniques used to create the perfect prehistoric hand silhouette



1 Tools for the job

To create a hand stencil, researchers think that prehistoric humans used hollow bones or reeds to blow paint through, and a shell to hold the paint in. The pigment used to make the paint was ground into powder and could be sourced from various minerals.



2 Making the paint

The powdered pigment was mixed with a binder in the shell using the reed or bone. Researchers trying to recreate prehistoric hand prints found that to make a paint thin enough to spray, the Palaeolithic painters likely used water as a binder.



3 Creating the stencil

The artist placed one hand on the wall, held one of the reeds/shells in their mouth, and held the shell and second tube (dipped in the paint) in their other hand. Blowing through one tube across the top of the other created a cloud of colour spray on the wall.



4 Finishing touches

When the artist removed their hand from the wall, they left a silhouette with colour all around it. More colours could be added with brushes, or a charcoal outline could be drawn around the hand. Bumpy walls could also help create a 3D effect.

Whose hands were they?

Experts can determine the gender of the person who made a stencil with over 90 per cent accuracy. The technique that is used is part of a study called geometric morphometrics. Digital versions of modern male and female hand stencils were made and used as a template when measuring those of prehistoric hands. The hands were then compared based on palm shape, which has been found to be a more useful indicator of gender than just measuring finger length and hand size. The study reinforced that both genders would often produce stencils. Researchers can also make an educated guess regarding the handedness of the artists, as the hand that is on the wall would most likely be their weaker side, and the dominant hand would be the one used to hold the pigment.



Hand stencils in Cueva de las Manos (Cave of Hands) in Argentina, created between 13,000 and 9,000 years ago



The world's weirdest pigments

Our artistic ancestors were quite resourceful



Mummy brown

A hugely popular pigment during the 16th century, this was made from the remains of ancient Egyptian mummies. Mixed with myrrh and white pitch, it made a reddish-brown colour.



Tyrian purple

This pigment was made from a dye extracted from murex shellfish. A symbol of imperial authority in the Roman Empire, it was used to colour the emperor's toga.



Lead white

Long before it was known to be poisonous, lead white was used as a paint pigment and also in makeup. One theory is that it contributed to Van Gogh's deteriorating mental health.



Uranium yellow

This yellow-orange pigment was used to create coloured glass and glazes for ceramics. However, this stopped when it was found to be a radioactive and highly toxic substance.



Carmine

Carmine is a deep red colour that has long been associated with royalty and nobility. It is made from the carminic acid that oozes out of some species of crushed beetles.

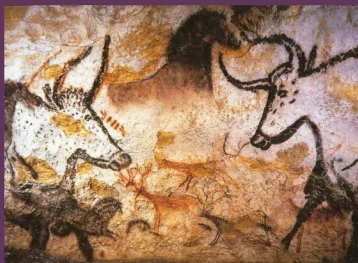
Cave art across the world

The best examples of parietal paintings across the globe, from France to Australia

LASCAUX

France / 18,000 - 13,000 BCE

With hundreds of paintings and drawings and over 1,500 engravings, Lascaux is one of the best sites for prehistoric art on Earth. The caves include depictions of bison, mammoths, aurochs, lions and wolves among others.



PETTAKERE CAVE

Indonesia / 38,000 BCE

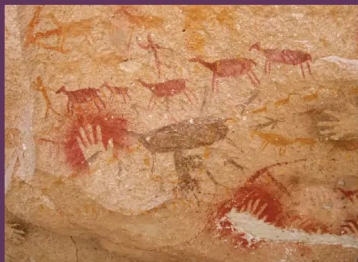
These Indonesian paintings are believed to be proof of prehistoric island-hopping in southeast Asia. The cave includes what are believed to be the oldest hand stencils on Earth.



CUEVA DE LAS MANOS

Argentina / 13,000 - 9000 BCE

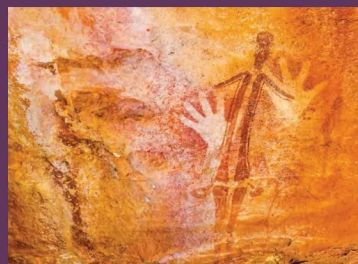
The Cave of Hands plays host to some of the oldest known cave paintings in the Americas. The artwork varies from hunting scenes to hand stencils and is red or black in colour.



KIMBERLEY

Australia / 50,000 - 5000 BCE

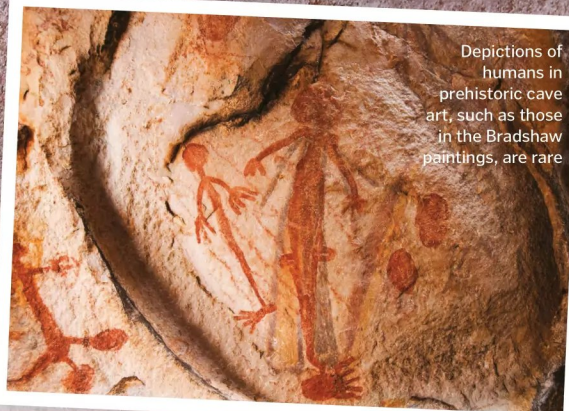
Known as the Bradshaw or Gwion Gwion paintings, the age of the art itself is difficult to determine, but it's possible that this cave is home to some of the oldest artwork of human figures in the world.



BLOMBOS CAVES

South Africa / 100,000 - 70,000 BCE

Archaeologists have unearthed the remains of what appears to be a rudimentary paint workshop in these caves. They found engraved blocks of ochre (shown on the right), shell 'palettes', bone 'spatulas' and grinding equipment.



Depictions of humans in prehistoric cave art, such as those in the Bradshaw paintings, are rare

"Some paintings in Europe are thought to be up to 40,000 years old"



INFLUENTIAL FIGURES

110 **Record-breaking royals**

Meet the richest, deadliest and longest-lived monarchs

114 **Leonardo da Vinci**

How the Renaissance polymath was much more than a painter

120 **Michael Faraday**

The scientist behind electromagnetic induction who inspired Albert Einstein



122 **Isambard Kingdom Brunel**

One of the greatest engineers of all time whose designs revolutionised transport

124 **Charles Darwin**

The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time

126 **The Wright brothers**

How these siblings played a pivotal role in the evolution of powered flight

128 **Guglielmo Marconi**

The father of radio who ushered in wireless telecommunications

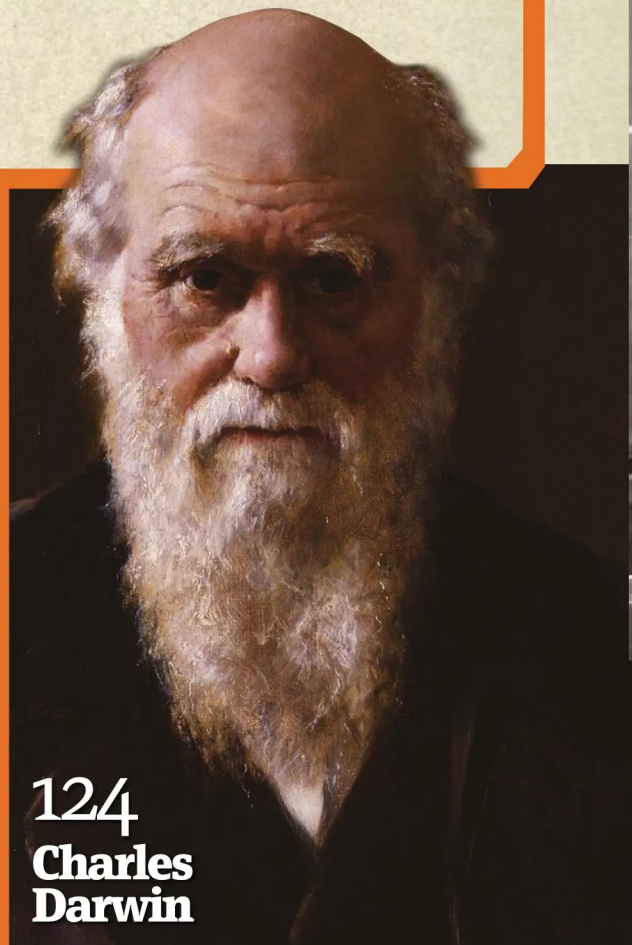
130 **Albert Einstein**

Meet the most influential physicist of all time

132 **Peter Higgs**

This physicist only shot into the limelight in 2012 with the discovery of the Higgs boson

110 **Record-breaking royals**



124
Charles Darwin



Peter Higgs
132

**Albert
Einstein**
130



128
**Guglielmo
Marconi**



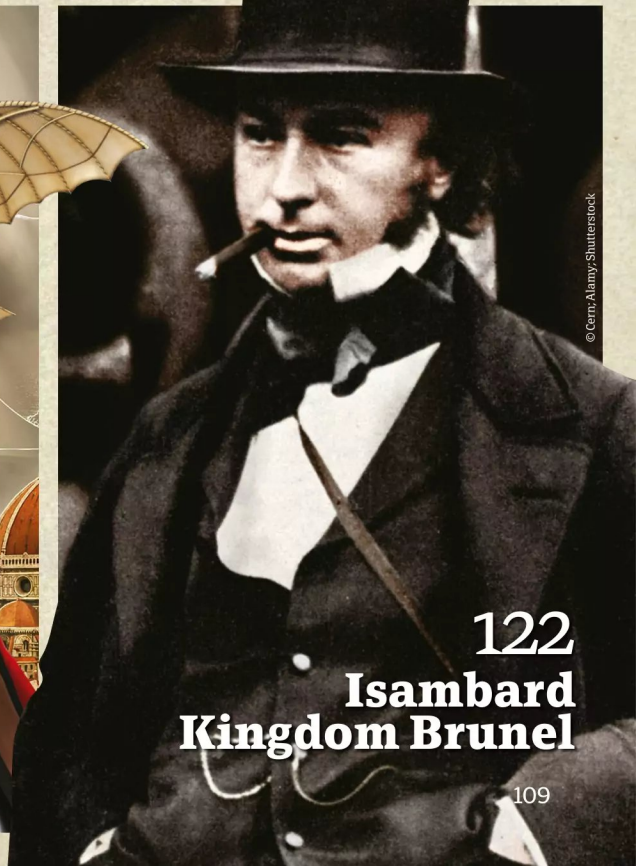
**Michael
Faraday**
120



**Leonardo
da Vinci**
114



122
**Isambard
Kingdom Brunel**





**Record-
breaking**

ROYALS

*Meet the richest, deadliest and
longest-lived monarchs and find out
who had the most wives, the most
money and the most heirs*





"According to Forbes, King Bhumibol Adulyadej's wealth amounted to £22 billion"



Longest reign

Sobhuza II

1899–1982 / Swaziland

Queen Elizabeth II became the longest-reigning British monarch in 2015, outstripping the record set by her great great grandmother, Queen Victoria. But this doesn't yet match global records.

The longest reigning European monarch was Afonso I of Portugal, who racked up an impressive 73 years and 220 days between 30 April 1112 and 6 December 1185. However, the longest verifiable reign in history belongs to Sobhuza II, Paramount Chief and King of Swaziland, who assumed his position at just four months old and remained on the throne for 82 years.

Even longer reigns are rumoured but challenging to confirm. It's believed that ancient Egyptian pharaoh Phiois II ascended his throne at the age of six in 2281 BCE and remained there for 94 years, and Min Hti, King of Arakan (now part of Myanmar), reigned from 1279 to 1374, a total of 95 years.

Shortest reign

Sultan Khalid bin Barghash

25–27 August 1896 / Zanzibar

There are two Guinness World Record holders for the shortest reign of a monarch, each spending less than half an hour on their thrones.

Louis-Antoine of France was heir apparent when Charles X abdicated after the July Revolution in 1830. He quickly abdicated too, passing the throne to Henry, Duke of Bordeaux, before fleeing to Britain.

Crown Prince Luís Filipe of Portugal also lost his throne to a revolution. His father Dom Carlos I was assassinated in the Lisbon Regicide of 1908, and Luís died 20 minutes later.

Neither of these princes actually had time to rule. The shortest reign of a ruling monarch goes to Sultan Khalid bin Barghash, who lasted just two days after taking the throne in Zanzibar. The British sent warships to siege his wooden palace, defeating him in the shortest war in history, the hour-long Anglo-Zanzibar War.



Richest

King Bhumibol Adulyadej

1946–2016 / Thailand

In 2012, the Guinness World Record holder for the richest royal was King Bhumibol Adulyadej, King Rama IX of the Chakri dynasty of Thailand. According to Forbes, his wealth amounted to £22 billion (\$30 billion), and his riches included the largest cut diamond in the world, a 545-carat jewel known as the Golden Jubilee Diamond.

King Bhumibol Adulyadej passed away in 2016, but no royal yet comes close to taking his title. The nearest is Hassanal Bolkiah, the Sultan of Brunei, who was reportedly worth £15 billion (\$20 billion) in 2011.



Most travelled

Queen Elizabeth II

1952–present / United Kingdom and the Commonwealth

Modern monarchs have the upper hand when it comes to global travel, and Queen Elizabeth II has visited more countries than any other royal. In her time on the throne she has racked up more than 1.6 million kilometres, despite, amazingly, not having a passport.

As of 2012 The Queen had made state visits to 116 different countries, including all 53 Commonwealth nations, and by 2016, she'd made 256 official trips in total. But there are some places that remain off-limits. The Queen has not visited Israel, Egypt, Argentina or Greece, the homeland of Prince Philip.



ABOVE: Queen Elizabeth II during a 1975 visit to Hong Kong
RIGHT: The Queen and Prince Philip in Canada, July 1970



Face on most currencies

Queen Elizabeth II

1952–present / United Kingdom and the Commonwealth

Queen Elizabeth II appears on coins in more than 35 different countries, including Australia, Bahamas, Belize, Bermuda, Canada, Cayman Islands, Cyprus, Dominica, Falkland Islands, Fiji, Gibraltar, Guernsey, Hong Kong, Jamaica, New Zealand, Nigeria, Mauritius, Papua New Guinea, Rhodesia, Seychelles, South Africa, St Helena, and the UK.



Queen Elizabeth II's portrait has appeared on banknotes all over the world

Most heirs

King Abdulaziz Al-Saud

1932–1953 / Saudi Arabia

King Abdulaziz Al-Saud founded Saudi Arabia in 1932 and had 45 sons, from whom every Saudi king is descended. The number of daughters he fathered is not known, but Saudi Arabia's royal family now has over 15,000 members. His eldest son, King Saud, had 52 sons and 54 daughters.



Deadliest

Nurhaci, Tianming Emperor

1616–1626 / Liaoning, China

Nurhaci, the Tianming emperor, spearheaded the overthrow of the Ming dynasty. He was leader of the Manchu people of northern China, who were fed up with the famine, silver shortages and tax rises of the early 1600s. He put together a declaration of war known as the 'seven grievances', and the result was one of the bloodiest conflicts in recorded history. The Ming dynasty was replaced with the Qing dynasty and, in the process, an estimated 25 million people died. In the battle of Yangzhou, lead by Nurhaci's son, Prince Dodo, 800,000 died.



Most wives

King Ibrahim Njoya

1886–1933 / Bamum (now western Cameroon)

Henry VIII is renowned for having six wives, but he doesn't come close to the record for royal spouses. King Ibn Saud of Saudi Arabia reportedly had 30; King Sobhuza II of Swaziland is rumoured to have had over 100; and King Ibrahim Njoya of Bamum had over 600.



Longest marriage

Takahito, Prince Mikasa Japan

This hotly contested record is currently held by Takahito, Prince Mikasa of Japan. He married Yuriko, Princess Mikasa, in 1941 and they were together for 75 years

until his death in 2016. However, Queen Elizabeth II and Prince Philip are fast catching up: they married on 20 November 1947.

Takahito served in China during WWII, becoming a harsh critic of Japan's Imperial Army



"Queen Victoria's empire was the largest in history"

Widest rule

Queen Victoria

1837-1901 / United Kingdom of Great Britain and Ireland, India

The British Empire has its roots in the 16th century, but it wasn't until the reign of Queen Victoria that it reached its peak. Her empire was the largest in history, covering more one-fifth of the world.

Competition with other European countries had driven the formation of British colonies, trading across the globe in tobacco, sugar, tea, silk, cotton, indigo dye and slaves. The first were set up in North America in the 1600s, then in Jamaica in 1655, and northwestern Canada in 1670. By 1661, the British began moving into Africa, settling an island in the Gambia River, and in 1788 the first settlements sprang up in Australia.

At the start of Victoria's reign colonies had appeared in South Africa, and during her time on the throne New Zealand and Egypt were added to the vast trading empire. In 1877 Victoria became Empress of India.





THE GENIUS OF

DA VINCI

So much more than just a painter, the famous Renaissance polymath invented a plethora of marvellous machines

Leonardo di ser Piero da Vinci was the epitome of a Renaissance man. While renowned as an artist, da Vinci was also a brilliant scientist and engineer. Beyond his famous paintings, such as *The Last Supper* and the *Mona Lisa*, da Vinci's journals reveal a range of studies and observations, from anatomy to astronomy, and palaeontology to philosophy.

The Renaissance ('rebirth') was a period of cultural revival, which began on the Italian Peninsula in the 14th century as the Middle Ages came to an end. Da Vinci was born in 1452 into a world that had become more accommodating to new ideas. A year after his birth, the capital of the Byzantine Empire, Constantinople (now Istanbul), fell to the Ottomans. As talented scientists and artists escaped the war-torn Bosphorus to seek safety in Italian city-states, the country became a hub of learning. One city the fleeing scholars settled in was Florence.

Here they were encouraged to study and invent by the ruling Medici family, who happily bankrolled learning centres all over the city. An intellectual and cultural revolution began; new technological and scientific ideas were spread with help from the recent invention of the printing press, as Europe began to catch up with academics from the Islamic world. It is likely that the inventions and creations of other Renaissance men like Mariano di Jacopo (also known as Taccola) and Filippo Brunelleschi influenced da Vinci, who revelled in the idea of Renaissance Humanism, a notion that encouraged learning and built on critical thinking methods that had stagnated in the Medieval period.

Da Vinci's most famous works are his paintings, but he was also a creative and talented engineer and inventor. The rediscovery of his codices in the 19th century revealed plans

for an array of contraptions, from battlefield tanks to flying machines. His ideas were influenced by classical antiquity and observations of the natural world. For example, a tortoise shell was the inspiration for his armoured car, while observations of birds, bats, flying fish and even plants contributed to the designs of his various flying machines.

His ideas were ambitious, but they were grounded in logical calculations based on scientific theories and mathematical principles. For the most part, these designs were only held back by the technological restrictions of the time. While many of da Vinci's manuscripts were inadvertently destroyed after his death, over 5,000 pages of his journals still exist today, providing us with a glimpse into the mind of a man ahead of his time. Leonardo da Vinci may have died nearly 500 years ago, but the legacy of his creativity and innovation lives on.

FLYING MACHINES

Da Vinci dreamed of mechanisms that would enable humans to soar through the sky

Aerial screw

An ambitious flying machine that helped inspire the modern helicopter

Scribbling in his notebook circa 1489, da Vinci envisioned a spiral-shaped contraption that could take to the skies. Possibly powered by hand cranks turned by four people, his writings suggested that the aerial screw could achieve flight by rotating quickly around a central shaft. Da Vinci believed that air could be compressed, so just as a screw bores into the ground below, his machine could 'bore' into the air above to lift his machine up off the ground.

Unfortunately, materials that were strong and light enough for the device to work were not available at the time. What's more, it would not have been able to fly for long, as once it was off the ground, the screw would no longer have a support structure to press against in order to keep spinning. It may never have made it off the ground, but da Vinci's innovative aerial screw design was the first to study the potential of a rotating spiral for flight.

"Da Vinci's most famous works are his paintings, but he was also a creative and talented engineer and inventor"

A weighty idea

Da Vinci's notes also specify the use of iron wires about five centimetres in diameter. It's predicted that this would have made the device weigh up to a ton

Materials

Da Vinci's notes mention that the helix section could be made of linen treated with starch. This would help reduce the cloth's porosity and make it more aerodynamic

Platform

Four men moved around the board, pushing their feet against the platform to turn the hand cranks, causing the rest of the mechanism to rotate

WOULD IT WORK?

Despite resembling a prototype helicopter, da Vinci's invention would not have made it into the air, partly because the power to weight ratio was so low.

Lift off?

One hurdle encountered in this study was to figure out how to produce high enough speeds to generate the required lift

Frame

Da Vinci intended for his machine to be constructed from a light and durable material, such as pine

Lever

The wing was curved and the pilot would use pulleys to flap rapidly and repeatedly

Ornithopter

Enthused by birds soaring in the air, da Vinci drew some inventive designs for mechanical wings

Da Vinci observed birds and other animals in flight, and became obsessed with the idea of a contraption that would allow humans to do the same. One of his ideas was an ornithopter, which was powered by flapping mechanical wings. Da Vinci wrote over 35,000 words and drew 500 sketches on flying machines. He understood that birds relied on both lift and propulsion to maintain flight, and that they balanced themselves with both wings and tail. He hinted at the idea of gravity and understood that flying machines had to be as lightweight as possible. His sketches demonstrate knowledge of aerodynamics, showing how airflow could be streamlined and how aircraft produce drag. The only drawback was the human body, which is simply not built to achieve flight on its own, nor muscular enough to power a mechanical engine for flight.

WOULD IT WORK?

Ornithopters with flapping wings have been built, both manned and unmanned. They can work with the help of an engine.



WAR MACHINES

Da Vinci devised a number of military mechanisms that could have revolutionised the battlefield

Armoured car

Da Vinci's concept could be considered a distant ancestor of the tanks of World War I

Incorporating past designs for armoured weapons, da Vinci's tortoise-like cannon system had the ability to move over flat terrain and would have been powered by an eight-man team. Oxen and horses were initially intended to provide the power, but space inside the car was limited. The operators were protected by a slanted and sturdy covering, and a turret on top was used as a viewpoint to help the drivers navigate. The armoured car was a good idea on paper, but a number of issues meant it could never have worked. Like the aerial screw, the human body simply didn't have the muscle power to move it, and the thin wheels meant the tank would easily sink in mud.

"His ideas were ambitious, but they were grounded in logical calculations"

Armour

The plated sloping design proposed by da Vinci was possibly superior to WWI tank armour, as the 45-degree angle would help deflect the impact of enemy projectiles

Power train

Da Vinci recommended that his armoured car be powered by a team of eight men, operating hand cranks that turned the wheels

Turret

The men inside would have likely accessed the turret with a ladder and used it to view the battlefield and signal tactics to allies

Cannons

Regularly placed around the car's circumference, the guns could fire in any direction on the battlefield

WOULD IT WORK?

If da Vinci's illustration was followed, the shafts would turn the wheels in opposing directions, preventing the car from moving. It's thought this was a deliberate error in case his designs fell into enemy hands.

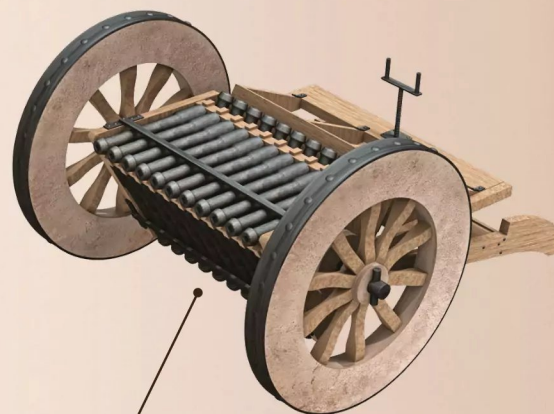
The bombard

Another weapon that da Vinci depicts in his notebook is a bombard that launched fragmenting ammunition



Rain of metal

Once it was fired, the cannonballs would separate into several pieces, raining down lethal shards of metal on enemy infantry



Wheels

Despite including studs on the wheels to add friction, it is likely the armoured car would have got stuck in boggy and uneven ground

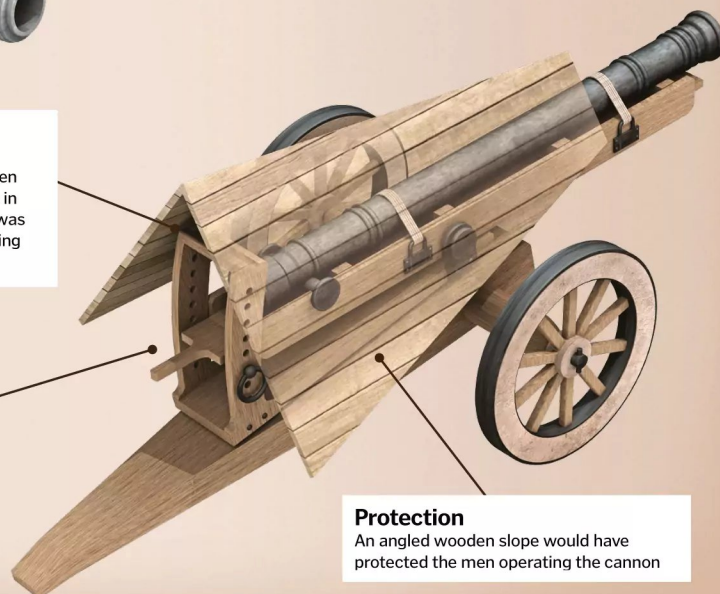
Machine gun

A multi-barrelled weapon that could unleash rapid-fire projectiles at hordes of enemy soldiers

Cannons were important in Renaissance-era artillery. Da Vinci aimed to add maneuverability and extra firepower with his concept of a multi-barrelled war machine that could fire a dozen cannonballs at once. With wheels on its side, the portable muzzle-loaded cannon had a rotating body with up to three revolving rows of guns. One could fire while the other two cooled and were reloaded. The recoil would have been fierce, so the machine was equipped with a support bulkhead that held the main body in place. In one of da Vinci's sketches, the barrels are arranged in a fan shape to give the weapon a wider firing range.

Recoil

The cannon was encased in a wooden structure to hold it in place. Although it was heavy, accurate firing was not difficult



Protection

An angled wooden slope would have protected the men operating the cannon

Springald

A cannon intended to eliminate specific targets from the battlefield

The springald was an artillery device that existed before da Vinci, but like many of his other creations, he built upon the idea. His version had the ability to fire in many directions both horizontally and vertically. An elevating arc moved the springald up and down, and when the desired height was achieved, it was held in place by a cylindrical peg. It could then be aimed to the left and the right. Iron and stone cannonballs, and even metal-tipped arrows were fired from the breech-loaded cannon.



HYDRAULIC MACHINES

Da Vinci's notebooks feature several ideas for complex yet workable devices powered by water

Paddleboat

This reciprocating-motion vessel was a huge advance on the oar-powered boats of the age

With the absence of internal combustion engines, boats and ships in the 15th century were powered either by wind or by oar. Writing between 1487 and 1489, da Vinci reasoned that a paddle-based mechanism that used reciprocating motion (repetitive back and forth movements) would be far more effective. By replacing the oars with paddle wheels, it would be easier for the boat to travel upstream.

The paddleboat wasn't an original da Vinci idea; Italian inventors Taccola and Francesco di Giorgio had both looked into the concept before, but this was the most realistic and workable proposal

yet. The operators would push down on alternate foot pedals, which powered a reciprocating-motion system, which in turn was transformed into rotary motion to turn the paddle wheels and propel the boat forwards. The principle was the opposite of a water mill, with the machine moving the water rather than the water moving the machine.



1 Pedal

The mechanism starts with the operator pushing down on one of the two pedals

2 Motor

The reciprocating motion produced by the pedal is transformed into rotary motion by a series of cranks, springs and gears

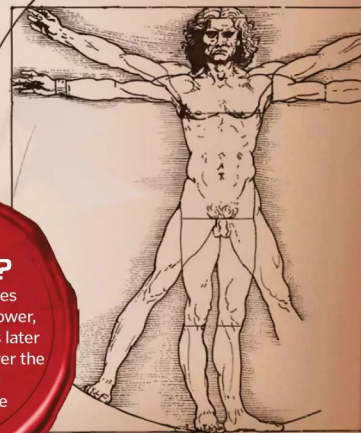
3 Paddles

The rotary motion produced by the motor turns the paddle wheels to propel the boat forwards

"The inventions of other Renaissance men most likely influenced da Vinci's own ideas"

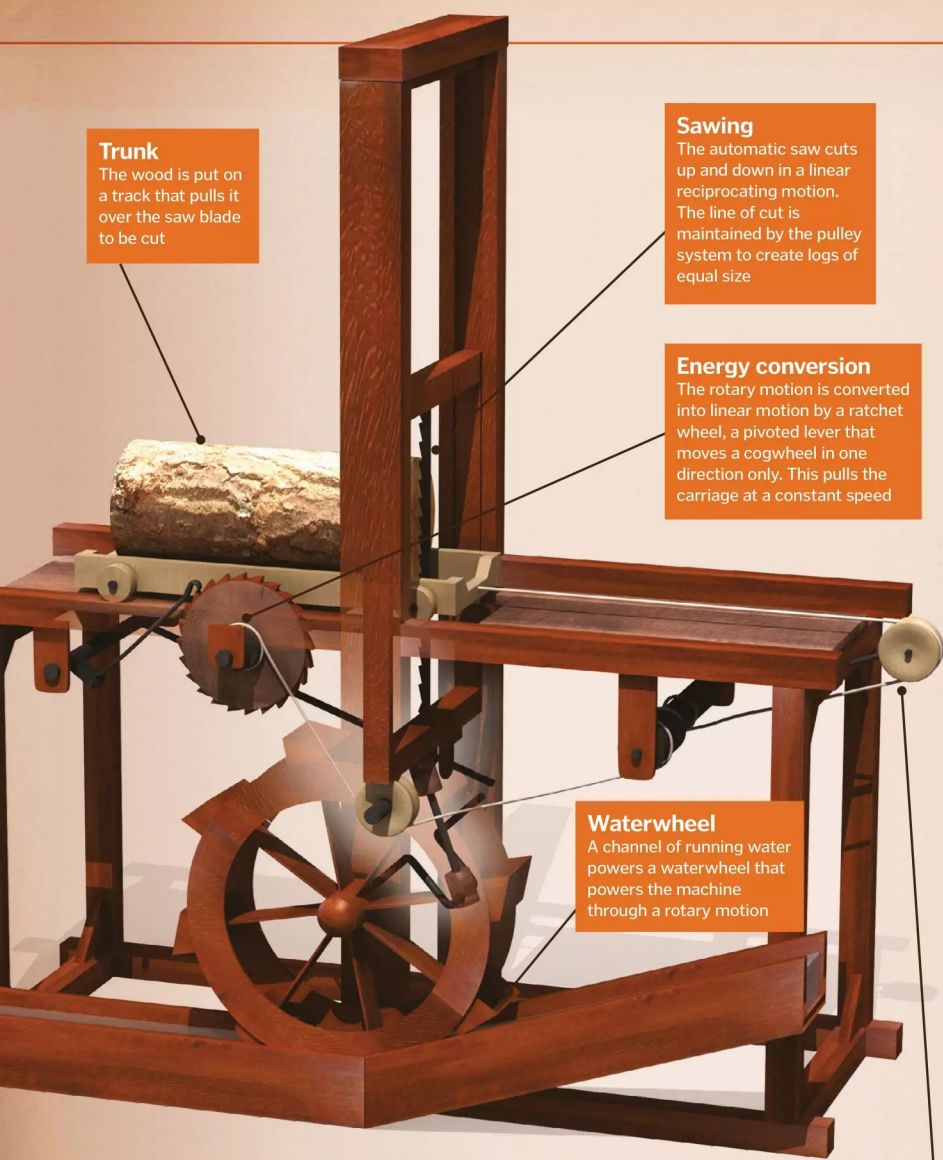
4 Reciprocation

The operators alternately press on the left and right pedals to keep the paddle wheels spinning



WOULD IT WORK?

Using steam engines rather than human power, the paddle wheel was later used extensively all over the world, notably in Mississippi paddle steamers.



Trunk

The wood is put on a track that pulls it over the saw blade to be cut

Sawing

The automatic saw cuts up and down in a linear reciprocating motion. The line of cut is maintained by the pulley system to create logs of equal size

Energy conversion

The rotary motion is converted into linear motion by a ratchet wheel, a pivoted lever that moves a cogwheel in one direction only. This pulls the carriage at a constant speed

Waterwheel

A channel of running water powers a waterwheel that powers the machine through a rotary motion

Pulleys

The mechanism is run using pulleys that gradually move the carriage as the wood is sliced

Mechanical saw

Another hydraulic invention that was designed to cut wood quickly and efficiently

Noted down circa 1478, da Vinci's mechanical saw was a rapid cutting device. The saw utilised the energy of a water mill to power the slicing of logs into wood. The wood would then be used for construction, particularly in war time, where it would be used to quickly build military bridges (these bridges were easy to transport and could be rapidly assembled across a body of water to allow troops to cross).

The saw's mechanism was relatively simple: a channel of running water turned a mill, and this rotary motion was transformed into linear reciprocating motion that powered the up and down sawing movement. The mechanism also powered pulleys and crankshafts that kept the log moving towards the saw. Like the paddleboat, the mechanical saw had been thought of before but not in this level of detail. Once again, da Vinci took a clever concept and improved it.

WOULD IT WORK?

The mechanical saw was one of da Vinci's least innovative but most workable concepts. Its automatic cutting system worked using the same principles as a standard water mill.

DA VINCI INVENTIONS USED TODAY



Ball bearings

First seen in a drawing in 1497, da Vinci based his idea on ancient Egyptians rollers that were used to transport huge stones up ramps to construct the pyramids.



Double hull

Da Vinci proposed the idea that a double hull would stop ships from sinking if its first was pierced by an enemy ship's ram, a weapon commonly used in naval battles.



Parachute

Da Vinci devised this combination of linen cloth and wooden poles 300 years before the first parachute test. His design was tested in 2005 and was proved to work.



Robot

Using a system of pulleys, weights and gears, da Vinci's robot was a moving suit of armour that could move its limbs, turn its head and sit down and stand up.



Air conditioning

After being asked to help ventilate a boudoir, da Vinci developed a mechanical water-driven fan in 1500 that can be seen as a precursor to modern cooling systems.



Michael Faraday

The scientist behind electromagnetic induction who played a key role in inspiring Einstein...



Faraday was a chemist as well as a physicist, who investigated liquefied gases, optical glass and electrolysis

Michael Faraday was born in 1791 to a poor family who couldn't afford to educate him. Few could have guessed that he would go on to massively advance our understanding of electricity and more. He learned to read and write at Sunday school, and subsequently became a bookbinder's apprentice in his teens.

Faraday loved to read and he worked his way through the books that he was binding, developing a keen interest in chemistry, electricity and magnetism. His newfound interest in science led him to attend a series of four lectures by chemist Humphry Davy, where he took extensive notes in the hope of securing employment at the Royal Institution. Eventually, his persistence paid off and he managed to get a job working as a laboratory assistant to Professor Davy.

Faraday worked for Davy for several years, during which time the pair travelled to Europe for their research. While with Davy, Faraday made several discoveries in the field of chemistry, including identification of the ring-shaped hydrocarbon benzene. He also made two new chemical compounds: hexachloroethane, which now forms the basis of military smoke grenades, and tetrachloroethylene, which is widely used to dry-clean clothes even to this day.

Faraday's major breakthroughs were not in chemistry though, but in physics. In 1820, Hans Christian Oersted discovered that an electrical current could produce a magnetic field. Faraday was convinced that the opposite must also be true, and began his most influential work on electromagnetic induction. His first discovery came shortly after, when he showed that by wrapping two insulated coils of wire around an iron ring a current could be transferred from one coil to another in a process known as mutual inductance.

Keen to further this research, Faraday continued investigating the electromagnetic properties of materials, and this led to his greatest achievement of all in 1831 – the discovery of electromagnetic induction (see 'The big idea' for more information).

Faraday's work on electromagnetism sparked the interest of other scientists and

A life's work

We highlight some key events from Faraday's electrifying career in the 19th century

1791

Michael Faraday is born in Surrey, UK, to James Faraday and Margaret Hastwell.

1805

Faraday starts work as a bookbinder's apprentice. During this time he develops an interest in science.

1813

He works as assistant to Professor Humphry Davy, making several advances in the field.

1821

Faraday discovers the principle behind the electric motor, using the idea of electromagnetic rotation.

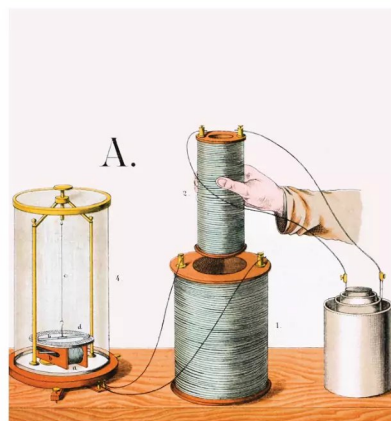
1824

He is elected a fellow of the Royal Society.



The big idea

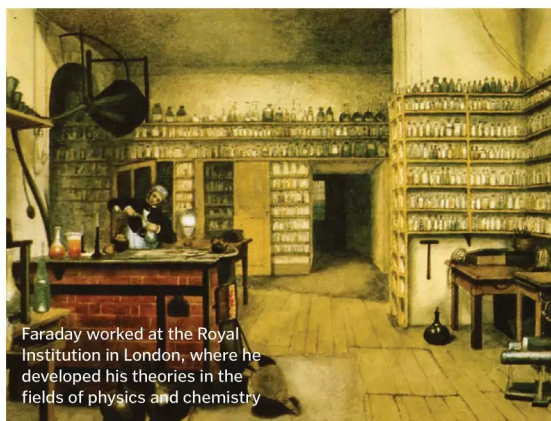
Faraday was a prolific scientist, but is best known for his work on electromagnetic induction. Faraday's Law states that a change in the magnetic environment near to a coil of wire will induce a voltage in the coil. Faraday developed a spinning copper disc, which rotates next to a static magnetic field (provided by a bar magnet). As the disc spins through the magnetic field, a potential difference is generated between the centre and the edge of the disc, creating a steady direct current. Faraday's disc was inefficient, but it provided the basis for the development of transformers, inductors, electrical motors and generators.



mathematicians, which led to William Thomson writing to him, suggesting that it was mathematically possible for magnets to alter the plane of polarised light. Faraday had been interested in this idea himself for a very long time, conducting experiments to show how light and magnetic fields interact with each other. This was one of the first steps towards the realisation that visible light is actually electromagnetic radiation.

Later in life Faraday's health declined, but even so, he stubbornly continued his lecturing at the Royal Institution. His incredible scientific contributions were officially acknowledged by the royal family and, in 1858, Faraday moved to a home in Hampton Court, granted to him by Queen Victoria. He died in 1867 and, having previously refused a burial site at Westminster Abbey, he was buried in Highgate Cemetery instead.

Faraday declined knighthood and presidency of the Royal Society twice



Faraday worked at the Royal Institution in London, where he developed his theories in the fields of physics and chemistry

Five facts: Michael Faraday

1 No one-trick pony

Faraday developed an early version of the Bunsen burner and also discovered the laws of electrolysis.

2 Nanoparticles

Faraday was the first to report nanoparticles' properties, noticing that gold colloids (sub-micrometre-sized gold particles dispersed in a liquid) have different properties to solid gold.

3 Modest man

He declined a knighthood offered by Queen Victoria, and refused to accept presidency of the Royal Society twice.

4 Christmas Lectures

Faraday founded the Royal Institution's (RI) Christmas Lectures. To this day, fun science demonstrations for children are broadcast every Christmas in the UK by the RI.

5 Competition

The Italian priest Francesco Zantedeschi and US scientist Joseph Henry were both working on electromagnetic induction too. Which of these men came up with the idea first is still contested to this day.

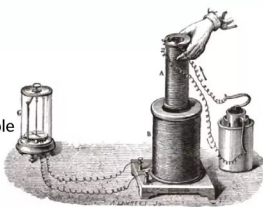
"Faraday worked his way through the books that he was binding, gaining interest in chemistry, electricity and magnetism"

1825

Faraday is appointed director of the laboratory at the Royal Institution, beginning the Christmas Lecture series.

1831

He discovers the principle of electromagnetic induction and invents the electromagnetic generator.



1858

Faraday moves to Hampton Court, awarded to him by Queen Victoria for his services to science.



1867

Faraday dies, aged 75, at his home in Hampton Court. He is buried in Highgate Cemetery.



© Corbis



Isambard Kingdom Brunel

Though not always successful, Brunel's designs revolutionised transport, and he is now remembered as one of the greatest engineers of all time



Isambard Kingdom Brunel revolutionised rail and water transport not just in the UK but all around the world

While an era of progress, the Industrial Revolution was also a time of trial and error. Those leading the way in technological advances attempted to make huge leaps forward, often resulting in failure, but sometimes incredible success. One of the greatest of the innovators of this time was Isambard Kingdom Brunel, born at the start of the 19th century. His father, Marc, was a French civil engineer, and encouraged his son to learn arithmetic, scale drawing and geometry. At 16, he became a watchmaker's apprentice.

In 1824 Marc was appointed chief engineer of a project to construct a tunnel under the River Thames. He hired his son as an assistant engineer, who later became resident engineer. The project was fraught with disaster, witnessing several incidents of flooding, as well as financial difficulties. At one point the operation was halted for several years and the tunnel bricked up. It was eventually opened in 1843 and is still in use today as part of the London Overground network.

The project transformed the young Brunel into a full-fledged engineer. In 1830 he entered a competition to design a bridge that would span across the River Avon in Bristol, and although rejected initially, he eventually persuaded the panel to appoint him as project engineer. Work on the Clifton Suspension Bridge commenced in June 1831, but just four months later the Queen Square riots drove investors away. Once again a project ground to a halt.

In 1833 Brunel was made chief engineer of the Great Western Railway, which would run from London to Bristol. It was then that he developed one of the most controversial ideas of his career – to use a 2.1-metre gauge (distance between the tracks) rather than the standard 1.4-metre gauge. He believed that this would allow the trains to run at much higher speeds, as well as provide a more stable and comfortable journey without as much rocking back and forth. For the

A life's work

Brunel made his mark on history – but what were the defining moments in this innovator's career?

1806

Isambard Kingdom Brunel is born in Portsmouth, UK, to French civil engineer Marc Isambard Brunel and Sophia Kingdom.



1827

Brunel is appointed resident engineer of the Thames Tunnel project in London, taking over from his father.



1830

He enters a competition to design a bridge to span the River Avon and is awarded first place.

1831

Work on the Clifton Suspension Bridge begins but financial difficulties bring the project to a halt.

1833

Brunel becomes chief engineer of the Great Western Railway, developing his idea for a wider track.

Clifton Suspension Bridge in focus

What feats of engineering ensured the bridge's survival to the modern day?

Towers

The two 26m-tall towers are not identical, as the Clifton tower has side cutouts and the Leigh tower pointed arches

Deck

The deck is made of timber sleepers some 13cm thick overlaid by planking 5cm deep

Foundations

The red sandstone-clad abutments contain vaulted chambers up to 11m high, reducing the cost of construction

Span

At the time of its construction, the bridge's 214m-span over the River Avon was the longest in the world

Chain

The bridge has three wrought iron chains on each side, which are anchored in tunnels 18m below the ground

rest of his life the efficiency of this design was heavily contested.

But none could contest the efficiency of his Great Western Steamship, which transported passengers from Bristol to New York. It was thought a steamship would not be able to carry enough fuel for the trip and have room for cargo. However, it completed its maiden voyage in 15 days, with a third of its coal remaining. Brunel was also a fierce proponent of propeller-driven ships and incorporated a propeller on his second ship, SS Great Britain. Considered the first modern ocean-going ship, it was made of metal, powered by an engine rather than wind, and driven by a propeller rather than a paddle wheel. Indeed, this vessel laid the foundations for a new era of transatlantic travel.

Brunel's personal life was a series of ups and downs too. Many say the stress of the Great Western Railway led to his early death in 1859. Soon after it was decided all railways in the country should revert to using the standard gauge. However, funds were also raised to complete the Clifton Bridge, which was opened five years after Brunel's death and is still in use.

The big idea

The Clifton Suspension Bridge in Bristol spans 214m between two 26.2m towers, which at the time was the longest bridge span in the world. In its design of chains and rods, Brunel had made a near-perfect calculation of the minimal weight required to provide maximum strength. The abutments contain a honeycomb of chambers and tunnels, some of which are 11m high, which reduced the cost of construction without compromising strength.



Brunel trivia

1 French connection

During his teenage years, Brunel attended school in France, but surprisingly his application to the renowned French engineering school École Polytechnique was unsuccessful, owing to the fact that he was a 'foreigner'.

2 River party

In 1827, after several incidents of flooding, Brunel held a lavish banquet inside the Thames Tunnel to help convince people that it was perfectly safe.

3 Beating the competition

Brunel's submission to the Clifton Bridge competition was initially rejected by the judge, Thomas Telford, who instead put forward his own design for the bridge.

4 Flip of a coin

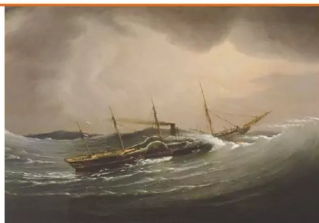
In 1843, while performing a magic trick for his children, a coin became lodged in Brunel's windpipe. In order to remove it, he was strapped to a board and turned upside down.

5 Commissioned by the lady with the lamp

In 1855 Brunel responded to a request from Florence Nightingale, known as nursing icon 'the lady with the lamp', to design a new hospital that would replace the unsanitary British Army Hospital in Scutari, Turkey, which he did successfully.

1838

The Great Western Steamship sails from Bristol to New York in just 15 days.



1843

The Thames Tunnel is opened to the public and the propeller-driven SS Great Britain is launched.

1852

Brunel's design for Paddington Station is constructed.



1859

Brunel dies on 15 September, ten days after suffering a stroke.

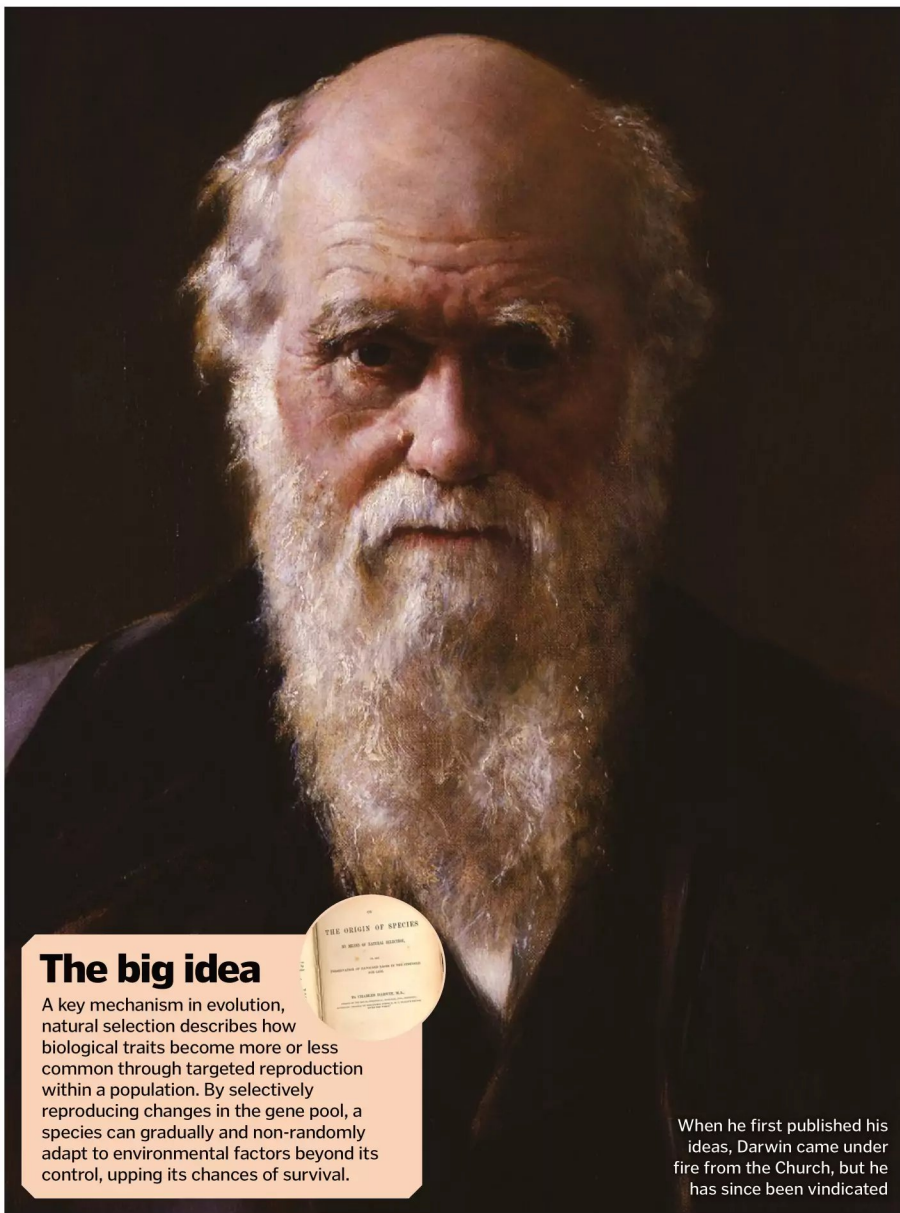
1864

The Clifton Suspension Bridge is finally completed as a tribute to Brunel by the Institute of Civil Engineers.



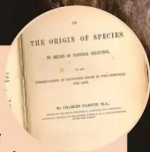
Charles Darwin

The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time



The big idea

A key mechanism in evolution, natural selection describes how biological traits become more or less common through targeted reproduction within a population. By selectively reproducing changes in the gene pool, a species can gradually and non-randomly adapt to environmental factors beyond its control, upping its chances of survival.



When he first published his ideas, Darwin came under fire from the Church, but he has since been vindicated

Charles Robert Darwin was an English naturalist renowned today for his theories of evolution and natural selection, both of which were introduced in his seminal work *On The Origin Of Species*. The book was both lambasted and celebrated on its publication. Early controversy stemmed from its apparent undermining of religious scripture, but it would become one of the most influential works of Western society, with the entire field of evolutionary studies arising from it.

Though *On The Origin Of Species* was published in 1859, Darwin originally conceived of evolution by natural selection shortly after an around-the-world tour starting in 1831. He embarked on the journey to expand his newly formed interest in natural history, spending the trip collecting specimens and analysing many interesting species, when not suffering from seasickness. During the expedition on HMS Beagle he collected over 5,436 skins, bones and carcasses of various creatures. His experiences and findings led him to question many of the accepted beliefs at the time concerning life's origins.

In 1838 he pinned down his theory of natural selection proper – see 'The big idea' boxout for more details. Over the next 20 years, he continued to refine it until he received a letter from fellow British naturalist Alfred Russel Wallace proposing a collaboration. The fact that both men shared the same ideas led to the joint publication of their research. While Wallace's hypotheses on the subject were detailed, his hands-on research was lacking and Darwin's extensive fieldwork won out, with history since attributing the theory largely to the latter.

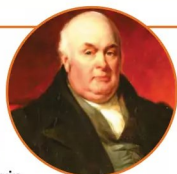
The publication of *On The Origin Of Species* the following year was therefore a landmark moment for Darwin – and for science as a

A life's work

Famous for describing the evolution of humanity, we chart Darwin's own evolution through the 19th century

1809

Charles Darwin is born in Shrewsbury, England. His parents are Robert (above) and Susannah Darwin.



1818

In June, Darwin goes to Shrewsbury School as a boarder, where he studies for seven years.

1825

Darwin signs up for medical courses at the University of Edinburgh with elder brother Erasmus.

1827

He is admitted to Christ's College Cambridge to study not science but divinity.

1831

Accepts an offer to join a voyage on HMS Beagle which sets sail on 27 December.



HMS Beagle spent just five weeks in the Galápagos Islands, but that was long enough for Darwin's research purposes



whole. To a degree it was a bringing together of various ideas that had already been mooted by other biologists but unproved. While Darwin did not supply concrete evidence for evolution, the work's lucidity and logic meant that, towards the end of the 1870s, the scientific community, and society as a whole, had accepted his views.

Darwin followed up this groundbreaking title in 1871 with *The Descent Of Man, And Selection In Relation To Sex*, where he applied his own evolutionary theory specifically to human's evolution from apes. This book was

incredibly popular from the word go, with a reprint ordered within just three weeks of publication. Three months after its release, 4,500 copies had been sold – a testament to his rising fame.

Darwin died on 19 April 1882 from heart disease and, after a request by his colleagues, was granted a state funeral at Westminster Abbey, buried alongside other famous scientists John Herschel and Isaac Newton.

Although some claim the significance of Galápagos finches to Darwin's theories has been overblown, more recent research indicates they are a good example of micro-evolution



Perhaps the most famous resident of the Galápagos, the giant tortoise

Five facts: Charles Darwin

1 Family guy

Darwin had ten children, though two died while still young. Three of his sons went on to become members of the Royal Society themselves.

2 On the money

Darwin is commemorated in the UK with his portrait printed on £10 banknotes, alongside a hummingbird and the ship HMS Beagle.

3 School of thought

The school that Charles Darwin attended as a boy, Shrewsbury School, still exists, but it is no longer in the same building, which has since become a library.

4 Name gets around

Due to Darwin's great achievements in the field of natural history, more than 120 species and nine different genera have been named in his honour to date.

5 No sea-lover

HMS Beagle took five years to circumnavigate the globe, but Darwin only spent 18 months on board. From the day it set sail, he was afflicted with terrible seasickness throughout.

"The publication of On The Origin Of Species was a landmark moment for Darwin – and for science"

1836

Lands back in England on 2 October and returns home to Shrewsbury.

1839

Marries Emma Wedgwood and has his first of ten children.



1858

Receives a letter from Alfred Russel Wallace who shares many of his ideas about the theory of natural selection.

1859

Publishes *On The Origin Of Species By Means Of Natural Selection, Or The Preservation Of Favoured Races In The Struggle For Life*.

1864

Receives the Copley Medal, the highest accolade from Britain's Royal Society.

1882

Darwin dies, aged 73, and is buried at Westminster.





Wilbur (right) and Orville attend the Belmont Park Aviation Meet, NY, in 1910

The Wright brothers

These siblings played a pivotal role in the evolution of powered flight and radically altered the path of aviation history

Wilbur and Orville Wright are two of history's most famous aviation pioneers who, through a series of experiments in the late-19th and early-20th centuries, created the first controllable, powered, heavier-than-air aircraft. Named the Wright Flyer, the plane was the culmination of over a decade's worth of research and trials that saw the brothers progress from custom-built kites, through to gliders and finally on to engine-powered aeroplanes. Together these talented siblings are generally credited with launching the age of powered flight.

Wilbur and Orville Wright were the sons of Milton Wright, an ordained minister of the Church of the United Brethren in Christ, and Susan Catherine Koerner Wright. The family lived in various locations including Richmond, Indiana; Cedar Rapids, Iowa; and Dayton, Ohio – the latter for the majority of the brothers' lives. Orville later explained that his father had encouraged both of them from an early age "to pursue intellectual interests and to investigate whatever aroused curiosity."

This encouragement led Orville and Wilbur into a diverse range of interests and expertise including printing, bicycles – which the pair sold and repaired for several years – and the construction of various machines from wood and metal. Both engineers and inventors, the brothers became well known for their academic and practical application of modern engineering, with Wilbur especially spending much time in his father's and public libraries.

One of their heroes was German gliding pioneer Otto Lilienthal, who up until his death

in 1896 had built and flown a series of aircraft to varying degrees of success. His death, however – which was the result of a glider crash – oddly spurred the brothers' interest in flight, with them writing to the Smithsonian Institution for suggestions on other aeronautical manuscripts. One of the museum's recommendations was the engineer Octave Chanute, a leading authority on aviation and civil engineering at the time.

With Chanute's help the brothers began conducting a number of aeronautical experiments. Crucial to their approach was the focus on control of the aircraft, advancing previous designs that could only fly in a straight line by introducing a helical twist across the wings in either direction. The brothers tested this configuration in 1899 and, after discovering that it allowed the acute control of a kite, began working on a full-scale model: the first Wright Glider. It was tested in October 1900 at Kitty Hawk, North Carolina, where although lifting off the ground, it produced disappointing results.

The Wright brothers refined their glider and tested it in 1901, then again in October 1902 after spending the summer undertaking a vast series of tests into more efficient wing designs. This third model was the breakthrough, with the glider performing exactly as predicted. The pair – who each piloted the glider in turn – racked up almost 1,000 flights between them over a two-month period, covering distances at Kitty Hawk of up to 190 metres.

Realising they had cracked both the aerodynamic and control issues that all of

The big idea

Prior to the Wright brothers' successful flight (pictured below), many other scientists and engineers had dreamed about and, to varying degrees of failure, attempted to build machines that could not only defy gravity, but do so in a controlled manner. Their failures left the idea of a non-dirigible method of flight as mere fancy, with materials, aerodynamics and energy supplies all seeming insurmountable obstacles.

What is testament to the Wright brothers' expertise is that they addressed each one of these issues with their aircraft in turn, solving in years what countless minds had failed to address in centuries. Examples include the testing of hundreds of wing designs in a custom-built wind tunnel to determine which shape best granted lift, designing and building their own four-cylinder internal combustion engine that was adapted for air travel, and recognising that propeller blades could be understood as rotary wings.



A life's work

The main milestones that led to the Wright Flyer taking off...

1867

Wilbur is born, with Orville arriving four years later.

1869

The Wright family move to Dayton, OH, due to the father's work commitments.



1892

Both brothers team up to open a bicycle repair shop. They begin building bikes a few years later.

1900

Years of research lead to the brothers testing the Wright Glider (right), an unpowered biplane with a forward elevator for pitch control.

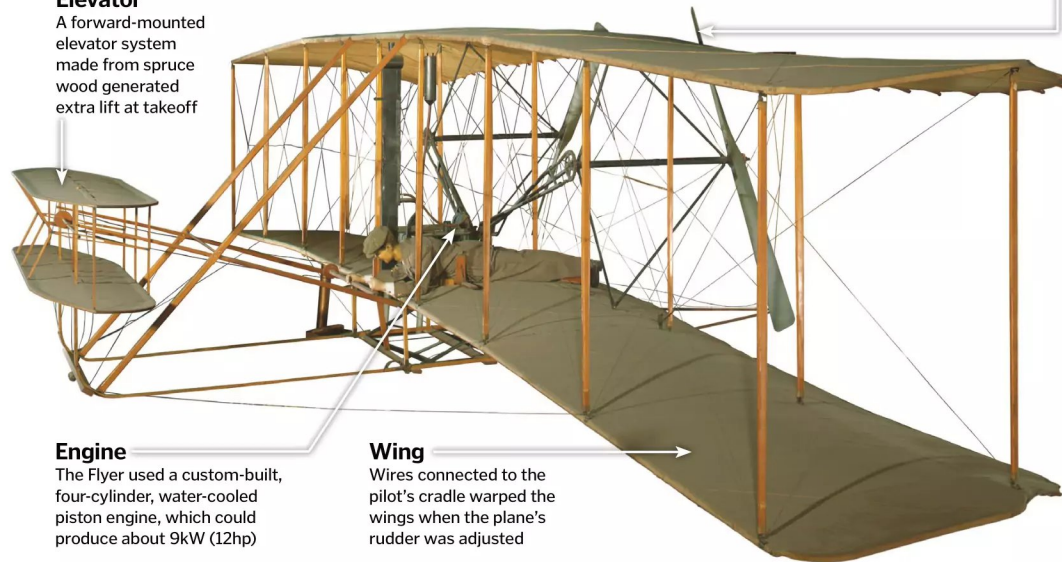


The Wright Flyer in focus

Take a closer look at the pinnacle of the Wright brothers' aviation careers

Elevator

A forward-mounted elevator system made from spruce wood generated extra lift at takeoff



Propeller

Two large propellers were driven by a sprocket chain drive, granting the Flyer a small amount of thrust

Engine

The Flyer used a custom-built, four-cylinder, water-cooled piston engine, which could produce about 9kW (12hp)

Wing

Wires connected to the pilot's cradle warped the wings when the plane's rudder was adjusted

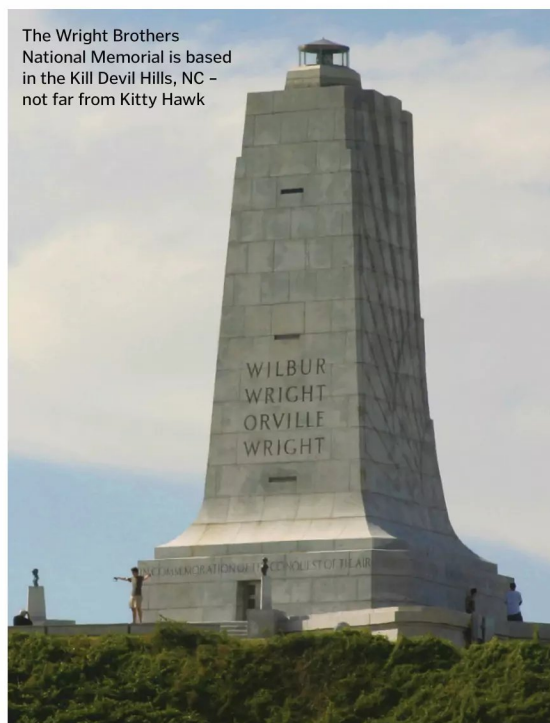
their predecessors had struggled with, the two brothers turned their attention to a power plant for the glider. In 1903 they built their own four-cylinder internal combustion engine and returned to Kitty Hawk to trial it.

Unfortunately the first attempt ended in the engine stalling during takeoff and the front of the plane getting damaged, but after a couple of repairs, the second flight ended in resounding success.

Lifting off at 10.35am on 17 December 1903, the Wright Flyer flew 36 metres, then 53 metres, followed by 60 metres before finally achieving a distance of 259.7 metres. This series of flights heralded a new era of aviation and propelled the Wright brothers and their aeroplane to worldwide fame.

"The brothers became well known for their academic and practical application of modern engineering"

The Wright Brothers National Memorial is based in the Kill Devil Hills, NC – not far from Kitty Hawk



Five facts: Wright bros

1 No college

Wilbur and Orville were the only members of the Wright family who didn't attend college. Orville spent the years learning the printing trade, while Wilbur helped out at the local church.

2 Lifelong bachelors

Neither of the Wright brothers married throughout their lives. Wilbur is recorded as once saying that he "did not have time for both a wife and an airplane."

3 Child's play

In their later lives, the Wright brothers attributed their fascination with flying machines to a small toy helicopter which their father had brought home one day from his travels.

4 Luminaries

Both of the brothers extensively catalogued their aviation experiments on paper, leading to Wilbur Wright delivering an official talk at the highly prestigious Western Society of Engineers in Chicago in 1901. The speech he gave was entitled, fittingly, 'Some Aeronautical Experiments'.

5 Hobby to business

In 1909 the Wright Company was incorporated with Wilbur as president and Orville as one of two vice-presidents. Orville sold the company three years after Wilbur's death in 1912.

1903

The brothers successfully fly the Wright Flyer in sustained flight at Kitty Hawk, NC. Its fourth flight covers 259.7 metres in just 59 seconds.



1909

The Wright Company sells the first-ever military aircraft, the Wright Military Flyer (right), to the US Army Signal Corps.



1912

Wilbur dies of typhoid fever on 30 May at 45 years old.

1915

Orville ends his leadership of the Wright Company by selling his shares to a group of financiers.

1920

Orville joins the board of the National Advisory Committee for Aeronautics – a precursor to NASA.



1948

Orville suffers a heart attack on 27 January and dies three days later in Dayton, OH, aged 76.



Guglielmo Marconi

Sometimes called the father of radio, this resourceful inventor's practical telegraphy system led to the widespread use of wireless communications

Marconi developed his radio equipment in the attic of his parents' home in Italy, with the help of his butler, Mignani



Guglielmo Giovanni Maria Marconi was a famous and widely respected Italian inventor who pioneered the development of wireless communication and long-distance radio transmission.

Often credited as the inventor of radio, Marconi was actually an astute businessman who combined, and built upon, the work of other scientists to develop a commercially viable method of long-distance communication.

His interest in electricity and physics began at an early age, and he was inspired by the work of scientists like James Clerk Maxwell, Heinrich Hertz and Nikola Tesla, among others.

In 1894, Marconi read the work of German physicist Hertz, who had developed equipment to send and detect electromagnetic waves over short distances. Marconi saw the potential for transmitting information using radio waves and set about developing a longer-range system to replace wire-based telegraphy.

Marconi began his experiments at his father's estate and with the help of his butler, Mignani, built equipment in the attic. Soon he could transmit radio waves over short distances, so he moved his experiments outdoors to develop the technology further. He found that increasing the length of the antennas – and arranging them vertically – increased the range of transmission so much that he was able to send and receive signals over distances of around 2.4 kilometres.

It was at this point that Marconi began to see the potential commercial applications of his experiments. Italy already had a well-established telegraph system though, with networks of wires extending across the country, and his applications for funding were dismissed. Undeterred, Marconi travelled to the UK. Britain had a powerful Royal Navy and was the world's greatest trading empire, and his thinking was that they might have use for his work in maritime communication.

A life's work

Tune in to some of the major events from the lifetime of this astute Italian radio pioneer

1874

Guglielmo Marconi is born in Bologna, Italy, to landowner Giuseppe Marconi and his Scots-Irish wife Annie Jameson.

1894

Begins to develop a method of transmitting telegraph messages without wires, using radio waves.



1896

Travels to London, where he gains the support of engineer-in-chief of the Post Office, William Preece.

1899

Sets up the first wireless link between Britain and France from Wimereux, France, to a lighthouse in Dover, England.



1900

Takes out his No 7777 'Improvements in Apparatus for Wireless Telegraphy' patent to protect his technological developments.

"The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted the most famous radio signals of all time"



Post Office engineers inspect Marconi's radio equipment before the first-ever transmission of radio signals over the open sea

Marconi gained the support of the engineer-in-chief of the British Post Office and, with his help, demonstrated his technology to the British government. During his first few years in England he gradually improved the distance of radio transmission – first on land and then over sea. His work excited the international community and stations were set up in France for the first radio crossing of the Channel.

As his technology continued to evolve, 'Marconi rooms' were installed in ships, containing a suite of wireless telegraphy equipment which enabled communication with land as well as other vessels. The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted perhaps the most famous radio signals of all time: 'CQD CQD SOS Titanic position 41.44 N 50.24 W. Require immediate assistance. Come at once. We struck an iceberg. Sinking'.

Marconi died in Rome in 1937 at the age of 63. He was given a state funeral and – as a tribute to his massive contribution to wireless communication – every radio station in the world fell silent for two minutes.

"Marconi saw the potential for transmitting information using radio waves"



The big idea

Marconi combined and modified the inventions of other scientists to develop equipment that could transmit radio waves over great distances. He used a spark-gap transmitter to generate radio frequency electromagnetic waves and a coherer receiver to detect them. A telegraph key enabled him to send radio waves in bursts, generating Morse code. Marconi discovered that the maximum distance of radio wave transmission varied according to the square of the height of the transmitting antenna – tall, vertical antennas were key.



Five facts: Guglielmo Marconi

1 Royal connections

Marconi installed radio equipment on Queen Victoria's royal yacht so that she could communicate with the Prince of Wales (Edward VII) while travelling.

2 Educated but unqualified

Marconi had no formal scientific qualifications, but had a keen interest in physics. At the request of his mother, he was mentored by physicist Professor Augusto Righi, who introduced him to radio waves.

3 Are you ready?

The first wireless radio transmission across the open sea was sent on 13 May 1897 over the Bristol Channel. The message travelled a distance of just 6.4 kilometres and read 'Are you ready?'

4 High-speed Morse

To be employed as a wireless operator by Marconi's Wireless Telegraph Company you had to be able to send and receive Morse code at a speed of 25 words per minute.

5 Lucky escape

Marconi was offered free passage on the famous doomed ship RMS Titanic, but decided to travel to America three days earlier on the RMS Lusitania because he had paperwork to do.

1901

Successfully transmits the letter 'S' in Morse code 3,380 kilometres across the Atlantic Ocean to Newfoundland.



1909

Receives the Nobel Prize in Physics – along with Karl Ferdinand Braun – for their contribution to wireless telegraphy.

1912

Marconi radio is used to save victims of the Titanic, and passes distress signals from the sinking ship to the RMS Carpathia.



1914

Joins the Italian war effort during World War I, where he takes charge of the military's radio service.

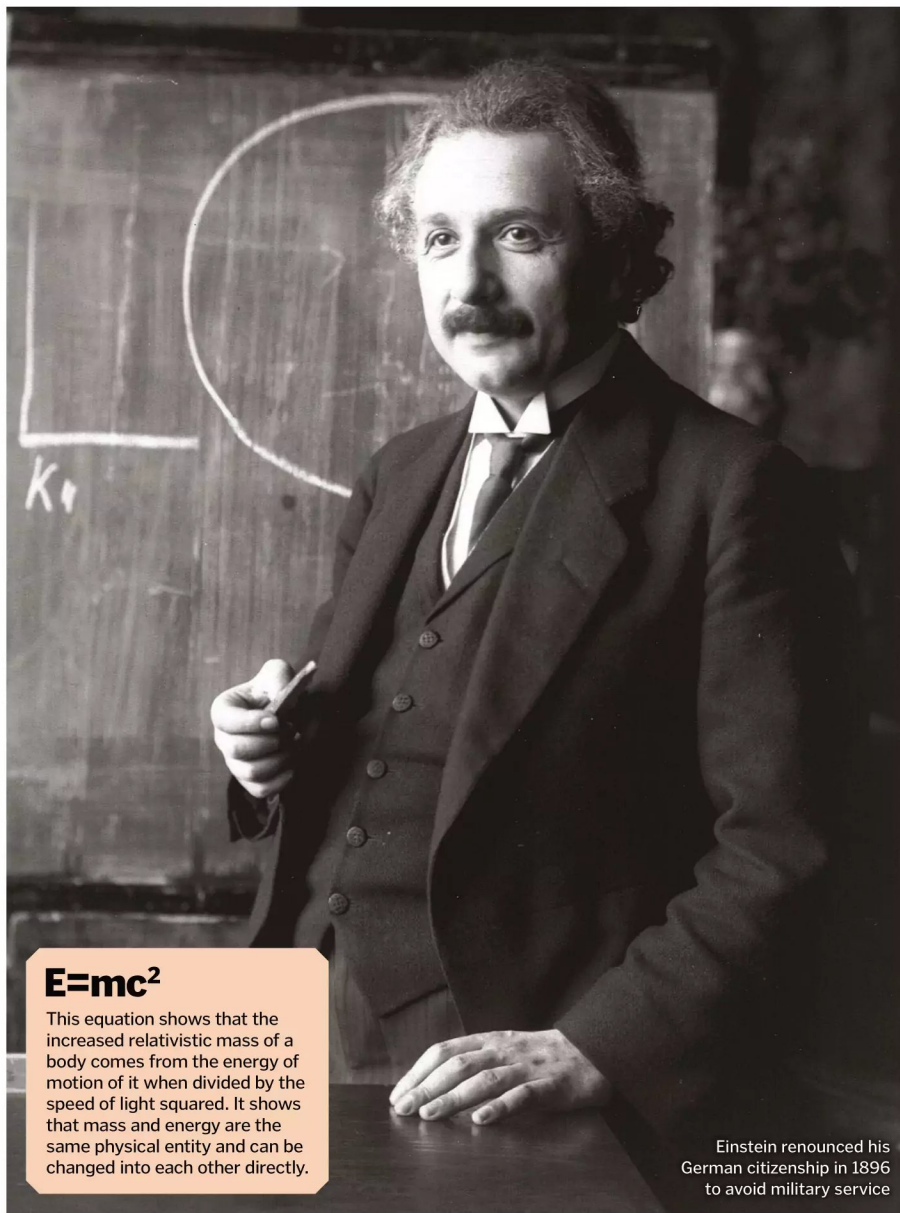
1937

Marconi dies aged 63. He receives a state funeral in Italy and all radio stations hold a two-minute silence in his honour.



Albert Einstein

The foremost scientist of his age, Einstein is considered the most influential physicist of all time



$$E=mc^2$$

This equation shows that the increased relativistic mass of a body comes from the energy of motion of it when divided by the speed of light squared. It shows that mass and energy are the same physical entity and can be changed into each other directly.

Einstein renounced his German citizenship in 1896 to avoid military service

Albert Einstein was born on 14 March 1879, in Ulm, Germany. He is considered the most influential physicist of the 20th century, formulating both the theories of special and general relativity, concepts that still underpin much in the fields of physics and astrophysics today. In 1921 he was awarded the prestigious Nobel Prize in Physics for his explanation of the photoelectric effect – a process where electrically charged particles are released from a substance when exposed to electromagnetic radiation.

Einstein's first real contact with science came when he was a young boy, instigated by his intrigue with his father's compass. Confused by the invisible forces that seemed to be acting upon the needle, he went through his early years fascinated by such forces. Spurred on by reading the work of Aaron Bernstein, which introduced him to the concepts of electricity and light, Einstein dedicated his later teenage years to the nature of light, writing a scientific paper entitled 'The Investigation Of The State Of Aether In Magnetic Fields'.

Despite a great love for the sciences, Einstein had a troubled education. He skipped classes while attending the Swiss Federal Polytechnic School, and his father's failed business led to much disruption, with Einstein having to move frequently. This led to a period where he was forced to take a position at the Swiss patent office in Bern, a role significantly less prestigious than his desired doctorate.

In hindsight, though, the position at the patent office was ideal, as the work left much time for him to theorise on the properties and nature of light. Then, suddenly, in 1905 Einstein made a breakthrough, starting what is now termed his 'miracle year'. In that time he published four papers: the first on the photoelectric effect, the second on the existence of atoms, the third introducing the

A life's work

We chart Einstein's phenomenal journey to becoming the most influential physicist

1879

Einstein is born on 14 March in Ulm, Germany.



1896

After avoiding military service, Einstein enrolled in a four-year mathematics and physics teaching course in Zurich.

1905

Einstein released four papers on the photoelectric effect, Brownian motion, special relativity and the equivalence of matter and energy.

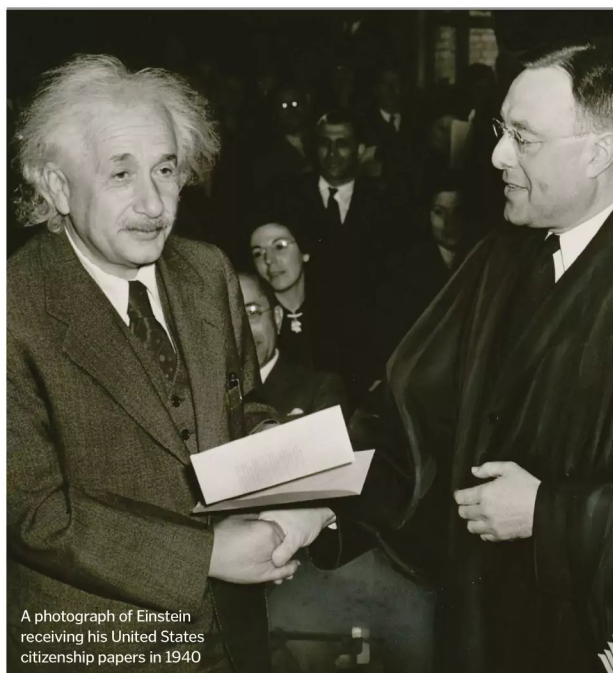
1906

Einstein receives a doctoral degree from the University of Zurich.



1908

He becomes lecturer at the University of Bern.



A photograph of Einstein receiving his United States citizenship papers in 1940



Einstein's former summer home in Germany was confiscated by the Nazis in 1933

mathematical theory of special relativity and the fourth on the theory of relativity. Famously, Einstein published the last paper almost as an afterthought, despite it containing the key equation for which he is famous: $E=mc^2$.

At first the scientific establishment ignored Einstein's papers. Fortunately, though, they caught the attention of the foremost scientist of the age: Max Planck, the founder of quantum theory. Through Planck, Einstein became a respected member of the international community, attending the prestigious Solvay conferences and being offered important positions at Europe's foremost universities.

After completing his theory of general relativity in November 1915, Einstein's work was interrupted by World War I. Being a life-long pacifist, Einstein opposed the war and spoke frequently on its folly. After its conclusion, Einstein toured the world, but his period away from Europe was soon to be made permanent, with Einstein fleeing Nazi Germany in 1933. He settled in America and was granted US citizenship in 1940.

While in America, though he was not immediately convinced that an atomic bomb

was possible, Einstein had encouraged the US government, including personally writing to President Roosevelt, to research nuclear chain reactions using uranium in response to German advances in the field. He did not work directly on the project to build a bomb, despite it being heavily based on his own work. According to reports, Einstein was on vacation when the first atomic bomb was dropped on Hiroshima, Japan. This action and its aftermath led to him undertaking anti-nuclear campaigns and lectures for the rest of his life.

Einstein's later years saw him pioneer numerous key theories including wormholes, multi-dimensional models and the possibility of time travel, as well as discovering his unified field theory. The latter was to be an all-embracing theory that would unify the forces of the universe and physics into one framework. The theory was never completed, however, with Einstein dying of an aortic aneurysm in 1955 before being able to finish his work.

"In 1905 Einstein made a breakthrough, starting his 'miracle year'"

Five facts: Einstein

1 Boy of few words

According to reports, Einstein seldom spoke as a child and when he did, it was very slowly. Accounts state he did this until he was nine.

2 Point of inspiration

Einstein's interest in science was reportedly sparked by his father's compass. At the age of five he thought there must be some force in the apparently empty space that acted on the needle.

3 Slow to start

Einstein did not receive outstanding grades while at school, and when he left he flunked the entry exam for the polytechnic institute in Zurich. Instead he went to work in the Swiss patent office first.

4 Nuclear pacifist

Einstein was a pacifist and while initially supporting the use of atomic weapons as a deterrent, he later chose to campaign for nuclear disarmament and world peace.

5 The man with two brains

After his death in 1955, Einstein's brain was removed for preservation by Thomas Stoltz Harvey in an attempt to discover what made him so intelligent.

1911

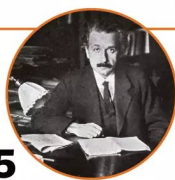
Einstein moves to Prague, where he acts as professor at the Karl-Ferdinand University.

1912

Einstein moves back to Switzerland, taking up a professorship at his alma mater, the Swiss Federal Institute of Technology in Zurich.

1915

Einstein completes his general theory of relativity.



1919

A solar eclipse provides dramatic observable evidence that his general theory of relativity is correct, making him a worldwide celebrity.



1921

16 years after its publication in 1905, Einstein wins the Nobel Prize in Physics for his work on the photoelectric effect.

1933

Einstein and his family flee from Nazi Germany to settle in the United States. He works at the Institute of Advanced Study at Princeton.

Peter Higgs

Well known in the scientific community for decades, it's only with the suspected discovery of the Higgs boson in 2012 that this physicist shot into the limelight

We can safely say that the 4 July 2012 discovery of a new particle, likely to be the elusive Higgs boson, had to be the biggest scientific announcement of that year. For most, it was enough to know that the Large Hadron Collider (LHC) – that huge, super-expensive particle accelerator in Switzerland – had given real weight to some decades-old but cohesive physical theory. Some impressive figures were released, then impossible speeds and inconceivably small theoretical particles existing for infinitely short expanses of time were mentioned, and our collective imaginations were captured. For

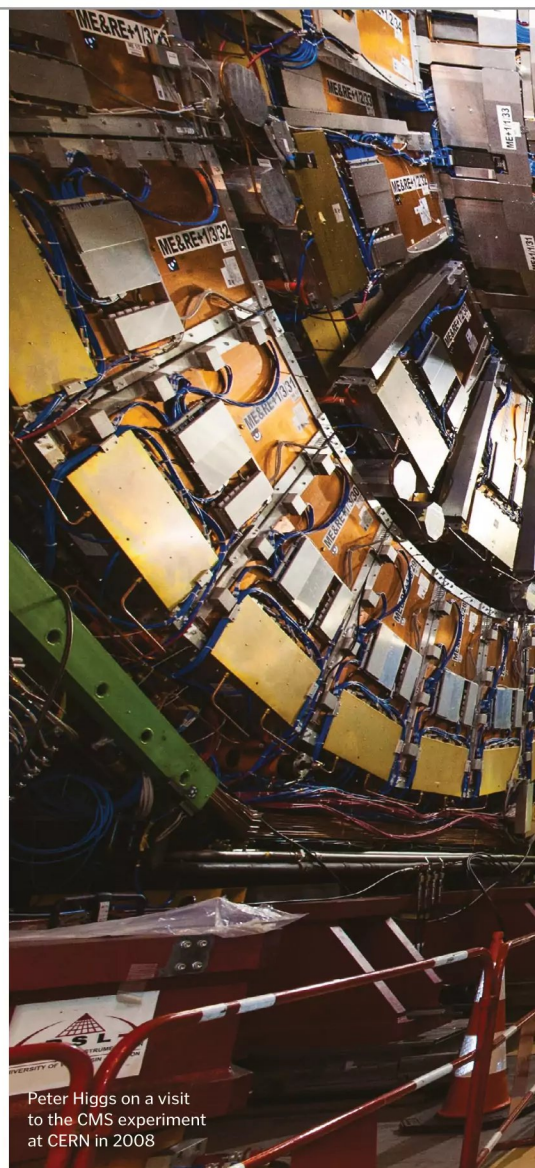
its namesake Peter Higgs though, it must have felt like the ultimate validation of his entire lifelong career.

Higgs was born in Newcastle-upon-Tyne, UK, in 1929. He graduated from King's College in the University of London with a first-class degree in Physics then went on to secure a Master's and finally a doctorate in 1954. It was during his work as a research fellow and a lecturer that Higgs began the basis of a paper that would help describe the very nature of mass, even if it was completely disregarded at first. Higgs' work began in quantum field theory – the surreal world of the forces that bind subatomic particles and an exciting new area at the time.

His first paper on the Goldstone boson was picked up and published by a physics journal edited at the only recently founded CERN in Switzerland that same year. To his dismay though, his next paper – finished in 1964 – was rejected on the basis that it bore no relevance to physics. This paper described the radical concept of what became known as the Higgs mechanism, a scalar field present in all points of space, which gives particles mass. The Higgs mechanism was independently discovered by several other leading physicists in the same year, however none of them made any mention of a massive boson, which Higgs had gone on to include in a revision of the same paper.

Higgs' ideas were used to describe the origins of particle mass by physicists Steven Weinberg and Abdus Salam in the late-Sixties – a solution to which had eluded the scientific community for some time.

By 1983 – the same year that Peter Higgs became a fellow of the Royal Society – the only unproven parts of this electroweak theory



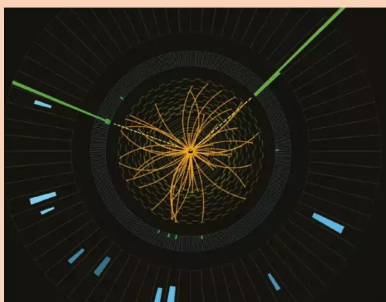
Peter Higgs on a visit to the CMS experiment at CERN in 2008

were the Higgs field and the Higgs boson, but it took him nearly 20 years and physical experiments of an unprecedented scale in the LHC and beyond, to finally draw a line under the Higgs boson.

Peter Higgs retired in 1996 from a career that also saw him win the Rutherford Medal and the Dirac Medal. In the wake of 2012's CERN announcement, he has received praise from many notable peers – including Stephen Hawking, who publicly recommended him for the Nobel Prize in Physics.

The big idea

The existence of the Higgs boson hasn't been proven absolutely, but CERN's experiments did confirm the existence of a new particle that is consistent with Higgs' theory. For most physicists, there's no doubt it's the Higgs boson. What this particle proves is the existence of the Higgs field, which allows the building blocks of our universe to gain mass and form stars, planets, galaxies and everything around us. Currently, it provides the answers to the last few burning questions in the Standard Model of Physics, and in the future it could prove integral to science.



A life's work

The big events that led to the discovery of this tiny particle

1929

Born on 29 May, the family moves around a lot as Higgs' father is a sound engineer for the BBC.

1954

Finishes his PhD at King's College London (right) and goes on to lecture at the University of Edinburgh.



1964

He describes the Higgs mechanism in a paper, which is rejected. He later revises it to include the Higgs boson.

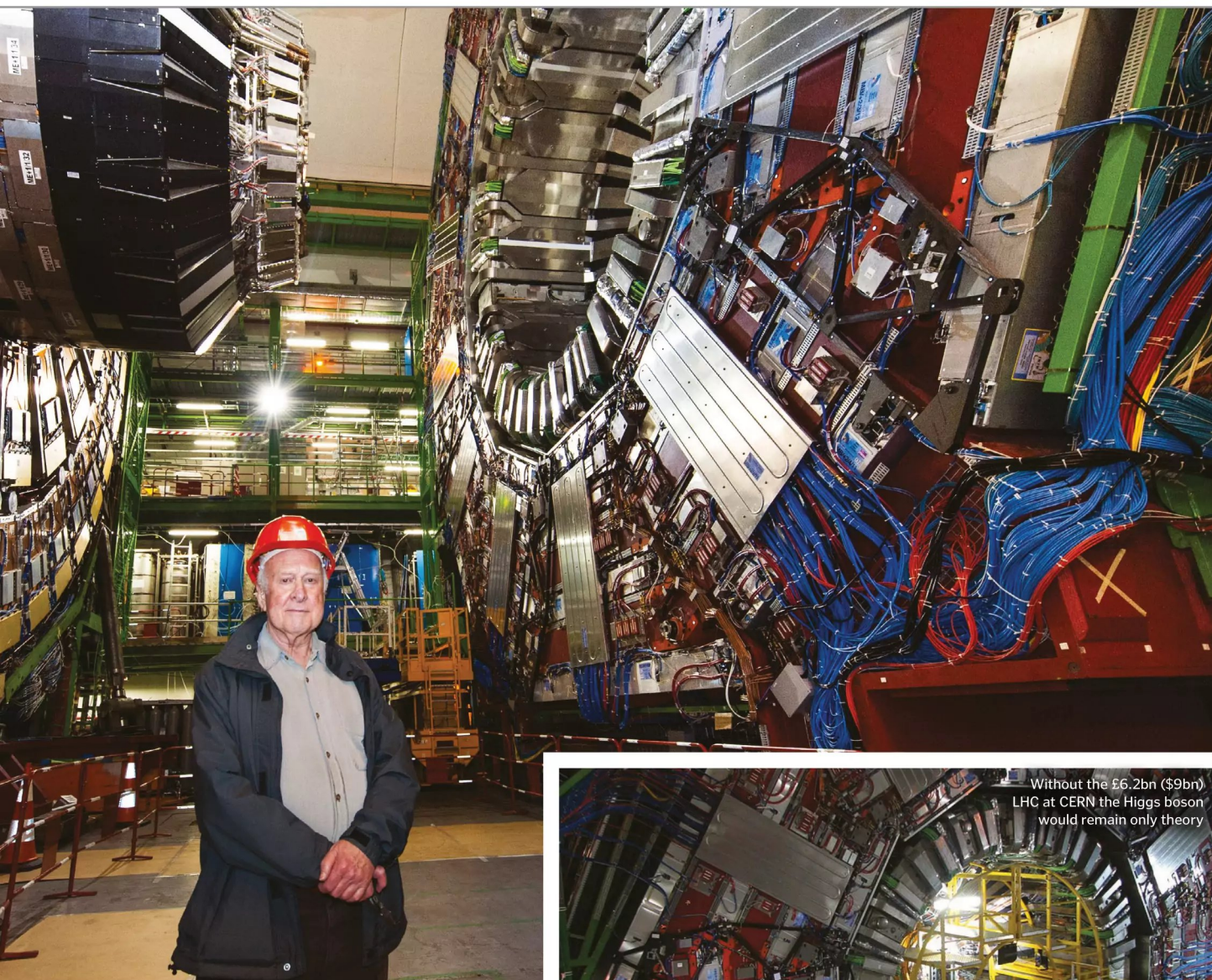
1983

W and Z bosons are discovered, leaving only the Higgs particle to confirm the electroweak theory. Higgs also enters the Royal Society.



1991

Higgs becomes a fellow at the prestigious Institute of Physics, London.



In their footsteps...

Ken Currie

The celebrated Scottish artist Ken Currie was commissioned by the University of Edinburgh to paint a portrait of Peter Higgs in 2008. He admitted to being inspired by Higgs' work - not claiming to understand his theory, per se, but grasping the sublime and 'beautiful' nature of his solution.

Sir David Wallace

Higgs was Wallace's advisor while he was studying a PhD in elementary particle theory. Formerly a researcher at Princeton University and a lecturer at Southampton University, it's for his work as director of the Edinburgh Parallel Computing Centre that he was awarded a CBE.



Without the £6.2bn (\$9bn) LHC at CERN the Higgs boson would remain only theory

"During his work as a lecturer Higgs began the basis of a paper that would help describe the very nature of mass"

1996

Higgs retires and becomes emeritus professor at the University of Edinburgh.



1997

He receives an award for his work in theoretical physics, named after a hero of his: theoretical physicist Paul Dirac (right).



2004

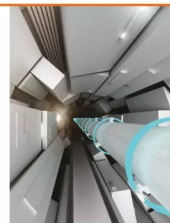
Another award - this time the Israeli Wolf Prize in Physics, though Higgs refuses to fly to Jerusalem to receive it on moral grounds.

2011

The results of CERN's initial experiments with the LHC in December are extremely positive, but more tests are needed to be certain.

2012

The strongest indication of a new particle with significant mass is announced by CERN in July. For his work, Higgs is made a Companion of Honour at the start of 2013.





157
**King-sized
croc**

PREHISTORIC

136 **Last days of the
dinosaurs**

How did an entire tribe of giant reptiles disappear from the face of the Earth?

144 **Fossils**

Discover life forms that lived millions or billions of years ago before being turned to stone

146 **The Ice Age**

Uncover the lost world and giant beasts of frozen Earth

154 **Prehistoric monsters**

The enormous ancient predators that ruled the land, seas and skies

146
The Ice Age

**Last days of
the dinosaurs**
136





**Marine
monsters**
156



Fossils
144



**151
Short-faced bear**



Gigantic fly
159



LAST DAYS OF THE DINOSAURS

AUROS

How did an entire tribe of giant reptiles disappear from the face of the Earth?

In 1677, English naturalist Robert Plot came face-to-face with a thigh bone belonging to an animal one and a half times his height. He thought the monstrous femur belonged to a giant. Since then, enormous bones have shown up in rocks around the world, but the creatures that they belonged to are nowhere to be seen.

From the spike-thumbed iguanodonts of England to the feathered microraptors of China and the iconic tyrannosaurs of the United States, dinosaurs ruled every corner of our planet, but between 66-64 million years ago they completely disappeared. The so-called KT extinction marks the transition between the Cretaceous and Tertiary periods of geological history.

During this catastrophic period, almost three-quarters of life on Earth withered away. Ammonites and belemnites disappeared from the oceans, along with dozens of species of nanoplankton, two entire groups of clams and many of the relatives of modern starfish, sea urchins, brittle stars and sea cucumbers. The ocean's top predators, the mosasaurs, also vanished. Winged pterosaurs went missing from the skies, and flowering plants died in their thousands, leaving behind a landscape dominated by ferns.

In 1980, Nobel Prize-winning American physicist, Luis Alvarez, and his son Walter noticed something unusual in the geological record. At around the time of the KT extinction, there was a band of the brittle, white transition metal, iridium. Usually rarer than gold, spikes of this unusual element appear in more than 100 places across the globe. The most likely explanation was an asteroid impact.

Iridium might be rare on our planet, but it's common in space rock. If an asteroid had collided with Earth, it could have kicked the metal into the atmosphere. As the dust settled, this would have formed a band in the rocks, marking the time of the impact.

At the level of this band there is also evidence of shocked quartz; a type of rock with distinctive microscopic features that form under intense pressure. There are also spheres of glass, made when molten rock is thrown up into the atmosphere and solidifies before it falls back to the ground. And there are vast quantities of soot, which could signal large-scale forest fires caused by burning debris from an extraterrestrial impact. Traces of the asteroid are greatest in North America. In Haiti there is a thick band of clay filled with glass spheres, and in the Gulf of Mexico tumbled rocks hint at an enormous tsunami, which could have been caused by an asteroid slamming into the planet.

To cause this level of destruction, the asteroid would have had to have been more than ten kilometres wide and travelling so fast that it



would have gouged a 100-kilometre-wide hole in the surface of the planet. It should have left an enormous crater, but the impact site was nowhere to be seen, and not everyone was convinced by the theory.

Earth was already undergoing a climate crisis; sea temperatures were rocking up and down, and water levels were rising and receding. What's more, asteroids aren't the only source of iridium, and extraterrestrial impacts aren't the only way that ash gets into the atmosphere. Even shocked quartz and glass spheres can be made by something other than an asteroid. All of these features could also be explained by volcanoes, and around the time the dinosaurs disappeared, there were some monumental eruptions.

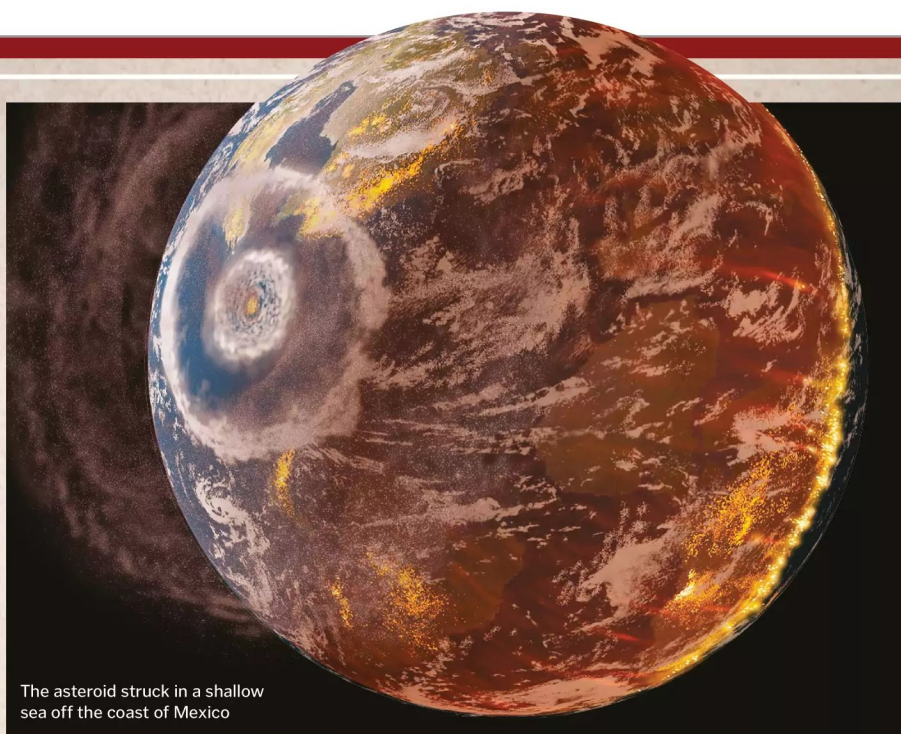
At that time, India was an island sitting on top of a volcanic hot spot. Bubbles of hot rock were rising from the Earth's mantle, which, unlike the crust, contains high levels of iridium. The magma poured out onto the surface, depositing more than 1 million cubic metres of new rock and forming vast lava plains now known as the Deccan Traps. As this happened, ash, sulphur and metal would have billowed and plumed into the air, potentially blocking out sunlight.

Both sides claimed the same evidence for their explanation of the trigger that caused the dinosaurs' demise, and without an actual impact crater, the Alvarez hypothesis had some gaps, but in 1990 geoscientist Alan Hildebrand found the smoking gun. Buried in a shallow sea off the coast of Mexico, there was a 180-kilometre-wide hole with strange gravity and an unusual magnetic field. It contained igneous rock, shocked quartz, spheres of glass and breccias – structures made from crushed rock glued together by mineral cement. It looked like the debris of an asteroid impact.

From the shape of the crater, it appears the asteroid came in at an angle, skidding debris up towards North America. The rock would have been fractured by intense vibrations, shooting molten debris into the air, and the thermal shock would have been so intense that everything within sight of the impact would have been totally obliterated.

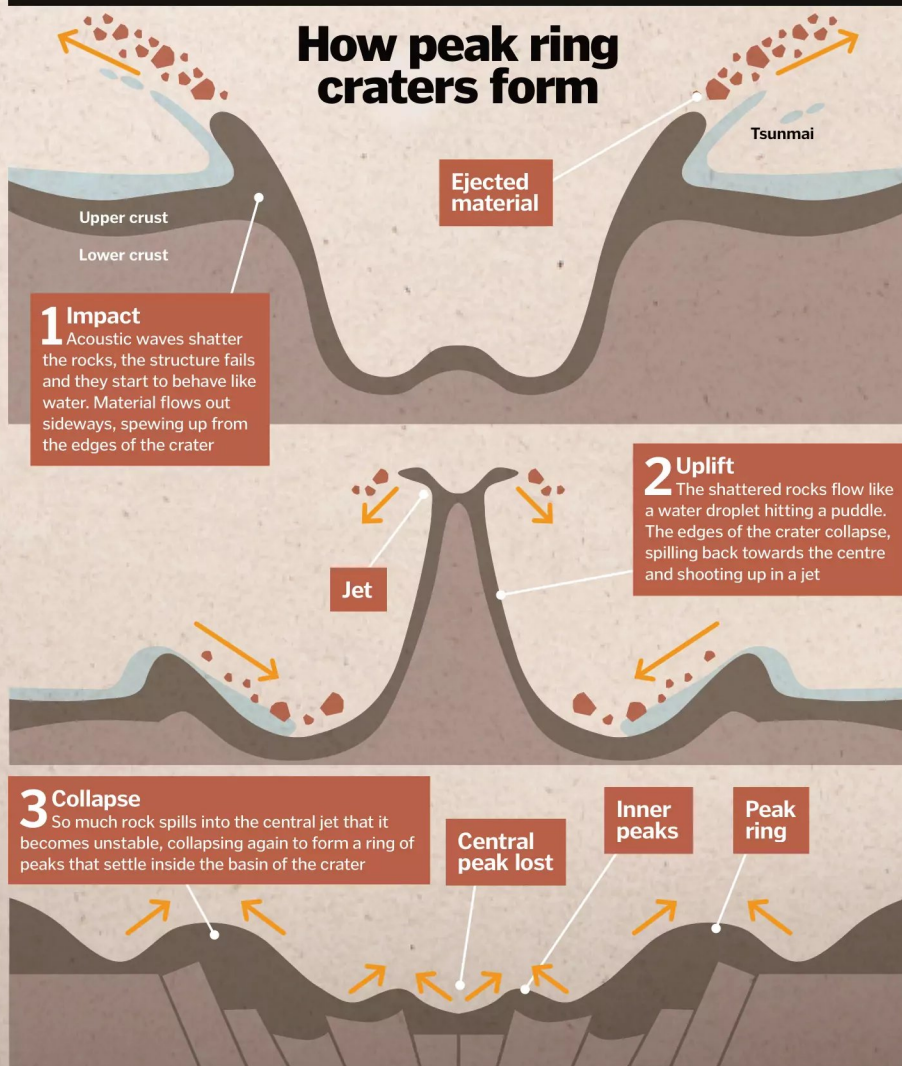
What followed would have been an earthquake of a magnitude unmatched by even the most powerful in recorded history. Vast tsunami waves would have been hurled across the oceans and debris from the impact site would have shot up with such force that some escaped the atmosphere. As the jettisoned rocks returned they would have burnt up, raining fire across the ground. Plants and animals in the surrounding area would have died instantly or within a matter of days.

Later, as fragments of ash, sulphur and soot from burning forests clogged the air, the world



The asteroid struck in a shallow sea off the coast of Mexico

How peak ring craters form



An extinction in numbers

10km

THE SIZE OF THE ASTEROID

180km

THE WIDTH OF THE CHICXULUB CRATER

65-66 million

THE NUMBER OF YEARS THAT HAVE
PASSED SINCE THE IMPACT

11

THE MAGNITUDE OF THE EARTHQUAKE THAT WOULD
HAVE SHAKEN EARTH AFTER THE IMPACT

BIGGEST RECORDED QUAKES COMPARED

- 9.5 VALDIVIA, CHILE, 1990
- 9.2 PRINCE WILLIAM SOUND, ALASKA, 1964
- 9.1 SUMATRA, INDONESIA, 2004
- 9.1 SENDAI, JAPAN, 2011
- 9.0 KAMCHATKA, RUSSIA, 1952

70%

THE ESTIMATED PROPORTION OF SPECIES
WIPED OUT BY THE IMPACT

**10
degrees**

THE RISE IN GLOBAL TEMPERATURE
FOLLOWING THE IMPACT

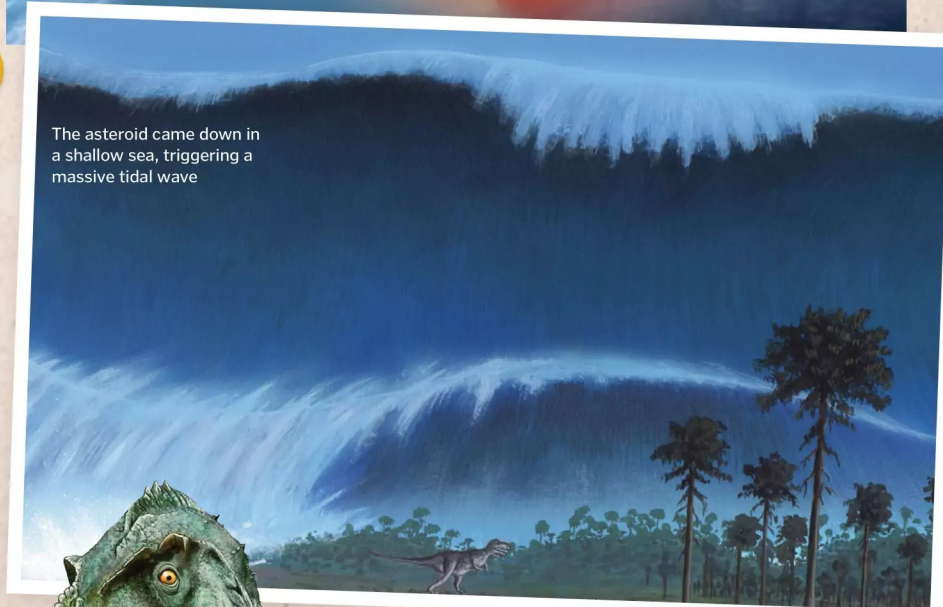
**100
million
megatons**

THE BLAST FORCE OF THE IMPACT

The impact shot
spheres of molten
glass into the air



The asteroid came down in
a shallow sea, triggering a
massive tidal wave



Glass and rock rained from the sky over North America

The impact

Within moments of the asteroid collision, the world completely changed

Flood

Waves up to 300m high tore across the planet

Instant fireball

Everything within 1,000km of the impact was consumed by flames

Raining rock

Rock from the impact rained down from the atmosphere, some molten, some on fire

Darkness

Ash and dust in the air blackened the sky, causing a twilight that lasted for months

Acid rain

Water washed particles of ash and sulphur out of the sky as acid rain

Quake

An earthquake of magnitude 11 shook the Earth, radiating out from the impact site

Global warming

Billions of tons of carbon dioxide and carbon monoxide were released by the impact. As the skies cleared, the world warmed

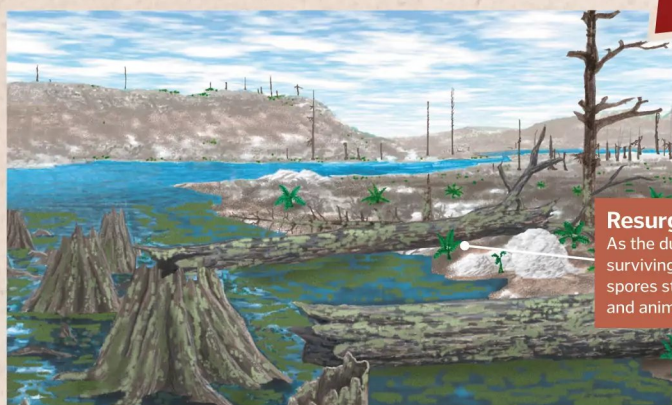
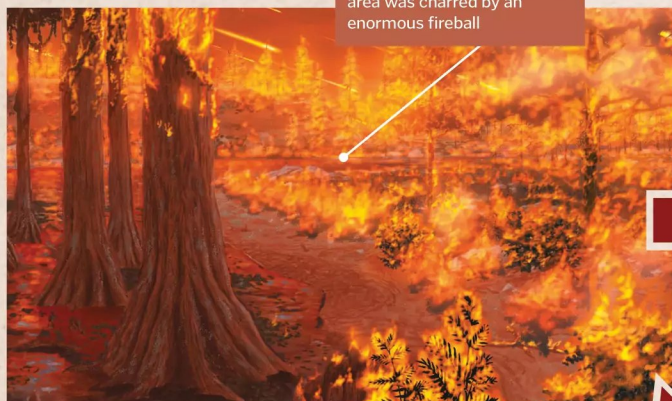


would have been plunged into perpetual twilight for weeks or even months. This 'impact winter' would have hit photosynthesisers hard, knocking out plankton in the seas and plants on land. With the bottom falling out of the food chain, entire ecosystems would have started to feel the strain.

The dust poured out of the sky as acid rain, but the ordeal was not yet over. The Chicxulub crater, as it is now known, sits right in the middle of a three-kilometre-thick layer of carbonate rock. It acts as solid storage for greenhouse gases like carbon dioxide, and when struck, it could have sent temperatures spiralling. As the air finally cleared,

Incineration

Everything in the surrounding area was charred by an enormous fireball



Resurgence

As the dust cleared, surviving seeds and spores started to grow and animals emerged

billions of tons of these greenhouse gases would have triggered rampant global warming.

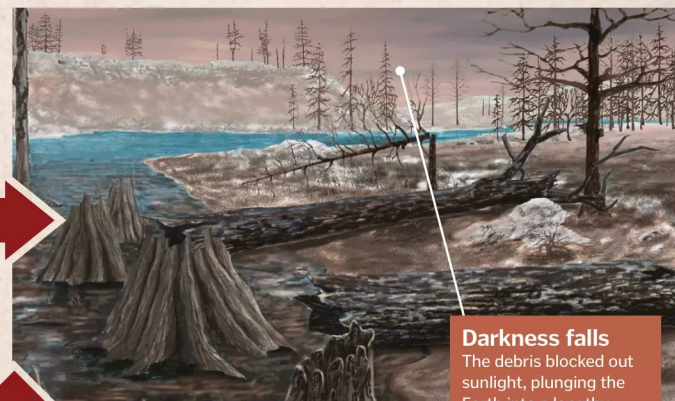
As Hildebrand said at the time of the discovery: "The Chicxulub impact, having presumably produced the largest impact crater on Earth, would have caused a mass extinction."

But even with the crater identified, some people still have their doubts. The most complete fossil record comes from North America, but even so, it's hard to create an exact timeline. Rock that old can't be carbon-dated, so it's not easy to tell if the dinosaurs all died at

once, or if the extinction happened gradually. And not all species were preserved, so it's

hard to piece together the ecosystem in enough detail to understand what caused it to fall apart. Specific conditions are needed to preserve the bones of fallen animals, and many perished without a trace.

Although there is good evidence that an asteroid did strike at Chicxulub, whether it killed the dinosaurs is hard to confirm. Some scientists argue that the impact happened about 300,000 years before the mass extinction, because some of the fossil evidence sits in layers of sediment above the impact line. It's possible that this chunk of sediment was thrown on top of the rocks by tsunamis triggered by the asteroid, but it's also possible that the sediment was laid



Darkness falls

The debris blocked out sunlight, plunging the Earth into a lengthy period of darkness

"With smoke from burning forests filling the air, the world was plunged into twilight"

What a difference a moment makes

The Chicxulub crater sits just off the coast of Mexico, in a shallow sea where the sediment was once filled with carbon and sulphur. When the asteroid struck, this rock shot into the atmosphere. 100 billion tons of sulphate particles and carbon – in the form of carbon dioxide, carbon monoxide and methane – entered the air. The sulphate first reflected the light, cooling the planet, but when it washed out of the sky as acid rain the carbon turned the atmosphere into a greenhouse and global temperatures climbed by degrees.

But a BBC documentary recently revealed that if the impact had come just seconds later, the rock would likely have settled in the depths of the ocean. Tsunami waves would still have flooded the surface, but the killer sulphur and greenhouse gases might never have entered the atmosphere and the dinosaurs may have been spared.



If the asteroid had come down in the deep ocean, the dinosaurs might have survived

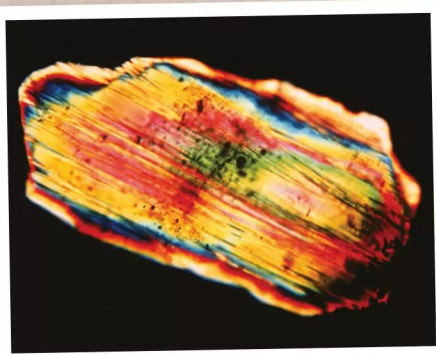
down gradually and that the extinction of the dinosaurs wasn't as rapid as it might first appear. There's evidence that animals burrowed into the soft rock and there's erosion that looks like it was created by flowing water.

To dig deeper into the role of Chicxulub in the last days of the dinosaurs, scientists have been drilling into the remains of the impact site. Chicxulub is the largest impact crater on Earth. The asteroid that caused this hole was so big that it created a distinctive ring of molten and fragmented rock inside the outline of the crater – the so-called 'peak ring'. Since the impact the crater has been buried in 17 metres of water and 500 metres of limestone.

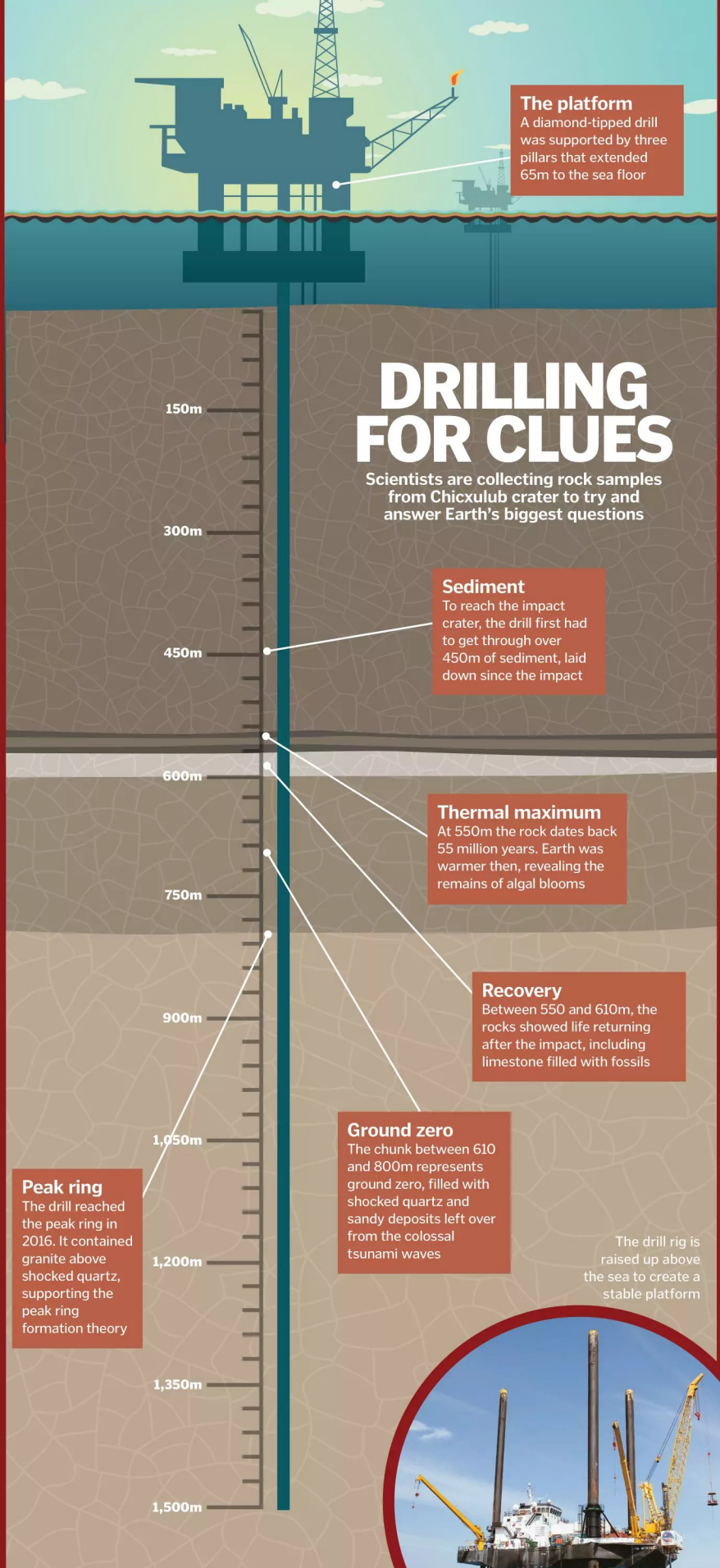
Between 2001 and 2002, the International Continental Drilling Program piled into the structure from the land in Mexico, revealing rock known as 'impact melt' that was likely made from fragments of rock that were shattered, spewed and then glued together when the crater formed. The drills also revealed evidence of hydrothermal activity caused by the huge impact, hinting that steam might have vented onto the crater for more than a million years after the asteroid struck.

In 2016, using a diamond-tipped drill, scientists bored into the structure again, this time targeting the peak ring to find out how it was formed and what happened in the aftermath. One startling discovery was the presence of pink granite in their drill samples. This crustal rock should have been down at a depth of 7,600 metres, but it turned up at 760 metres, evidence of the intense shock that crumpled and shook the Earth below.

There are still many unanswered questions about the extinction of the dinosaurs, and the reality is that we won't ever know the truth of what happened for sure. The Chicxulub crater is thought to have spawned one of the most devastating extinction events of all time, but evidence being gathered from the remains of the crater hint that impacts can nurture life as well as destroy it.



The stress lines inside shocked quartz are caused by intense pressure



Not only did the KT extinction make way for the rise of mammals; the most recent drilling expedition revealed a large network of channels that were filled with warm water after the impact. At first they would have been too hot for even the hardiest of life forms, but as they cooled, microscopic life could have thrived in the warm, damp cracks, nourished by minerals leaching out of the rocks. And this has exciting implications for the origins of all living things.

Though life was already firmly established by the time the Chicxulub asteroid arrived, the crater gives us a glimpse into the kinds of conditions that might have been present on the ancient, lifeless Earth. Charles Darwin thought that life might have begun in a "warm little pond", where minerals mixed with water and organic molecules. Asteroids are stuffed with organic compounds that could have provided the ingredients for the chemistry life to begin, and if they set up warm, wet, mineral-rich niches when they strike the Earth, they could be the parents of Darwin's little ponds.

As we speak, NASA's OSIRIS-REx is hunting the asteroid Bennu (which scientists have suggested could collide with Earth in the 22nd century) in search of clues as to whether asteroids could have helped life to begin on Earth billions of years before the dinosaurs even existed.

While it is unlikely that we will ever know exactly how the dinosaurs died, their demise might shed light on an even bigger question – how did they get here in the first place?

"Microbes may have thrived, nourished by minerals leaching out of the rocks"

Mass extinctions

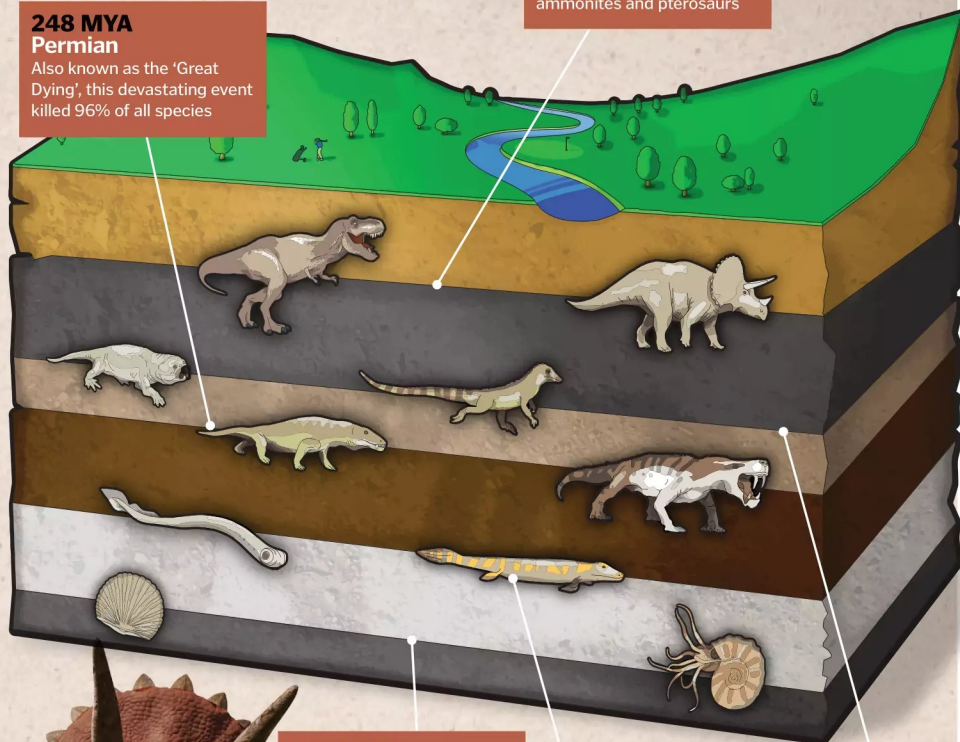
The KT extinction was not the first and it won't be the last

248 MYA Permian

Also known as the 'Great Dying', this devastating event killed 96% of all species

66 MYA Cretaceous-Tertiary

70% of species were killed, including dinosaurs, ammonites and pterosaurs



443 MYA Ordovician-Silurian

85% of life disappeared, most of which was in the sea

359 MYA Late Devonian

75% of all species succumbed, including reefs and shallow sea creatures

200 MYA Triassic-Jurassic

Half of all species expired, including significant numbers of marine animals

Making way for mammals

The KT extinction event devastated the Earth, but without it, we wouldn't be here today. As the dominant land animals struggled to survive in a world charred by debris, blackened by sulphur and soot and heated by greenhouse gases, tiny mammals were shielded in their burrows. Many birds, reptiles and amphibians were also spared; saved by their small body size and flexible, often insect-based, diets. Some freshwater species also fared well; their food chain includes detritus – nutrients released by decomposition – which washes into streams and lakes, providing a steady supply of fuel.

As Earth started to recover there were gaps in the food chain for these animals to fill and the survivors spread out to take the places of the dinosaurs. Over time they evolved to become the huge variety of species that we see today.





Fossils

Discover life forms that lived millions or billions of years ago before being turned to stone

Extinguishment is a fact of life that, sooner or later, spells the end for all species. But dead doesn't mean forgotten. The evidence might have remained hidden for millions or even billions of years but, in the fifth century BCE, Greek philosopher Xenophanes discovered the fossils of sea creatures and recognised what they were.

We'll look at exactly how it happens later, but put simply, a fossil was a living organism, which, following its death, turned to stone. And these

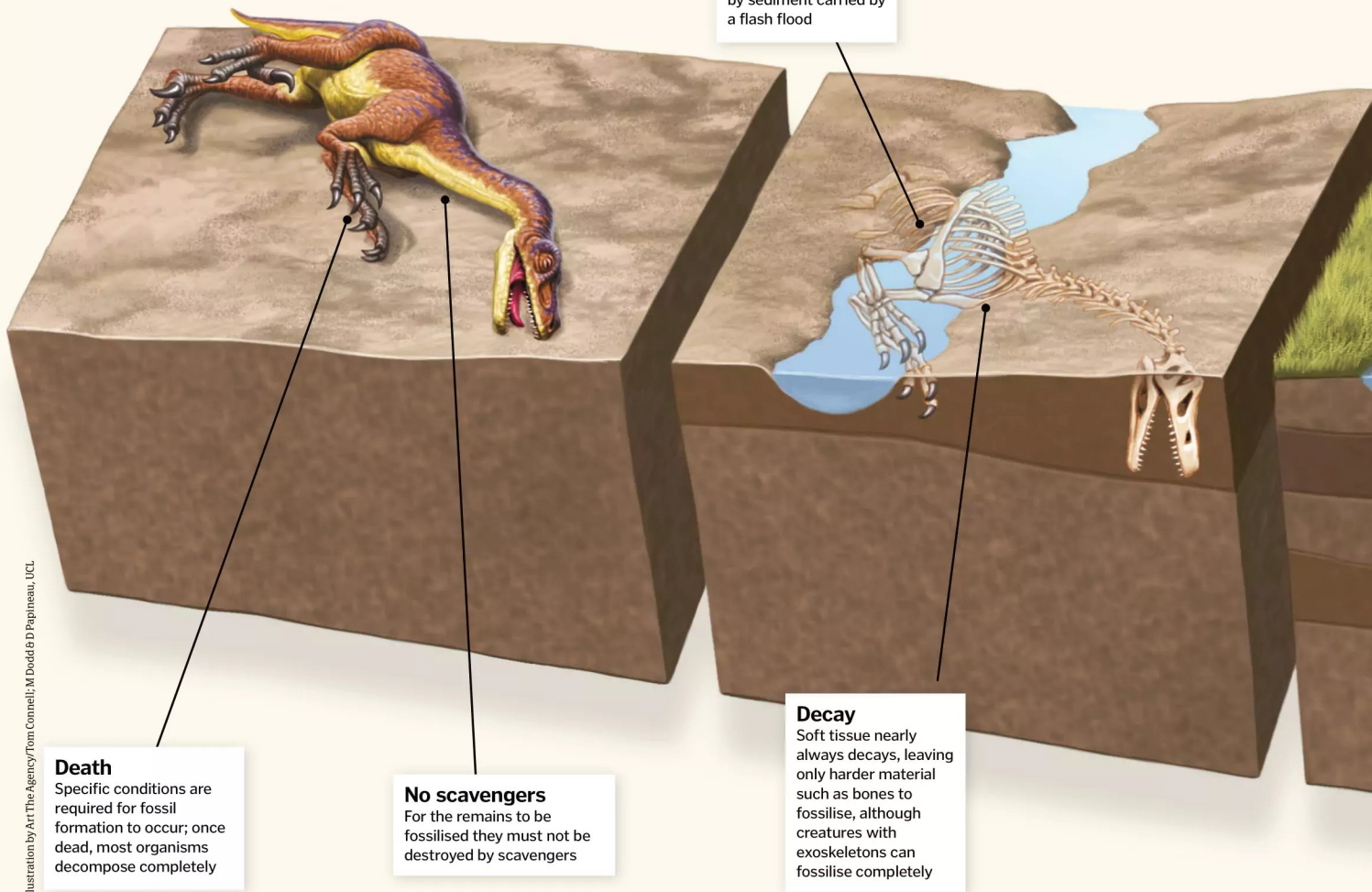
records can teach us so much. Having found marine fossils on land, for example, Xenophanes was able to say with confidence that the sea once covered what was then dry land. Over the years, fossils have taught us a great deal about Earth's history, and the discoveries continue today.

For example, recent discoveries of fossils dating back to the dawn of our planet, when the Earth was an apparently inhospitable place, have fuelled speculation that life could have started on Mars at about the same time.

Mention fossils and many people think instantly of dinosaurs. These huge lizards might have left some of the largest, most impressive fossils, but they are not nearly the oldest, nor do they have a monopoly on providing a spectacle. The world of fossils is a varied one encompassing wonders as extraordinary as trilobites: large woodlouse-like creatures that crawled on the bed of tropical seas; brightly coloured petrified wood from long lost forests in Arizona; and coprolite – fossilised droppings.

The formation of fossils

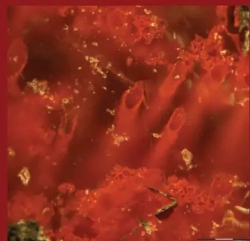
How a living organism can be turned into stone and preserved for millions of years



Top five fossil discoveries

The oldest fossils

Scientists at UCL have announced the oldest fossils yet. The tube-like structures, found in Canada, are about 3.77 billion years old and grew around deep-sea vents.



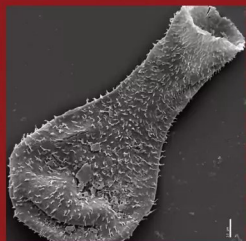
The largest fossil

Fossilised bones from Argentina represent the largest known dinosaur. The titanosaur was nearly 40 metres long, stood 20 metres tall, and weighed about 70 tons.



The smallest fossils

Not all fossils are massive; some are so small you need a microscope to see them. Marine microfossils known as Chitinozoa, for example, can be as little as 0.05mm long.



The rarest fossils

Soft tissue usually decays before fossilising, so fossils of creatures with no hard parts are rare. However, researchers at Berlin Free University recently found octopus fossils.



The family tree

Hominin fossils, such as the famous Lucy specimen, have enabled scientists to study human evolution. These findings have helped to shed light on our ancient cousins.

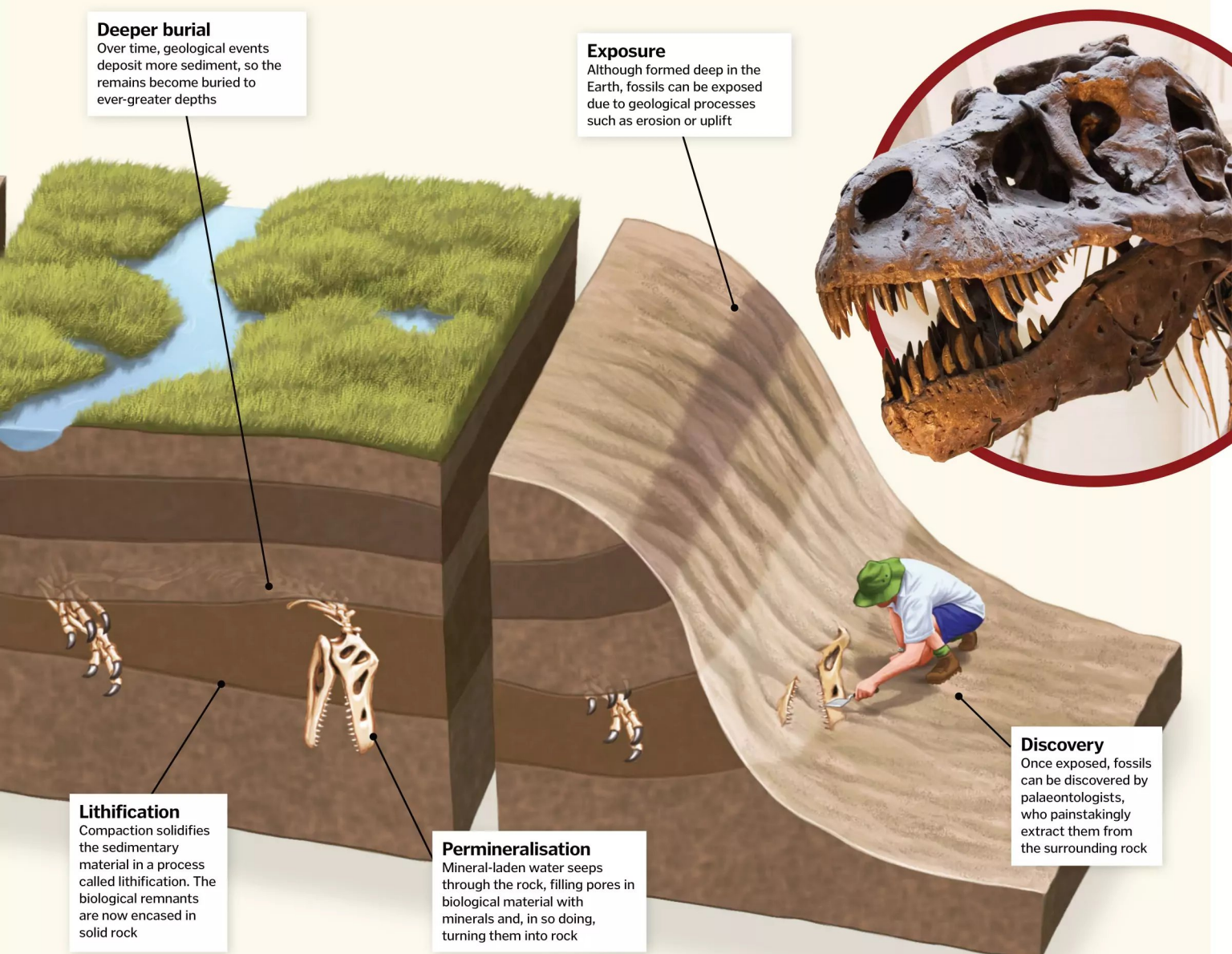


Deeper burial

Over time, geological events deposit more sediment, so the remains become buried to ever-greater depths

Exposure

Although formed deep in the Earth, fossils can be exposed due to geological processes such as erosion or uplift



Lithification

Compaction solidifies the sedimentary material in a process called lithification. The biological remnants are now encased in solid rock

Permineralisation

Mineral-laden water seeps through the rock, filling pores in biological material with minerals and, in so doing, turning them into rock

Discovery

Once exposed, fossils can be discovered by palaeontologists, who painstakingly extract them from the surrounding rock



THE ICE AGE

Uncover the lost world and giant beasts of frozen Earth

For most of Earth's history, the planet has been free of ice, even at the poles.

However, for the last 2.4 billion years, Earth has been cycling in and out of freezing ice ages. For millions of years at a time, temperatures plummet and large areas of the globe become trapped under sheets of ice. These glacial periods start gradually. Snow falls during the winter, and fails to melt in the summer, and over time, layer upon layer is built up. The white surface reflects sunlight back into space, and a cycle of cooling begins.

Vast glaciers form at the poles, creeping inwards towards the equator, and Earth's water is locked away into slowly moving ice. As it creeps along, it carves great scars into the landscape beneath. When Earth's water freezes, sea levels drop, revealing land once hidden beneath the oceans. Winds and currents change direction, and even those places untouched by ice undergo significant climate change.

There have been at least five ice ages so far, the first of which transformed the entire planet into a giant snowball. However, within these periods of extreme chill, there have been occasional bursts of warmth. During each ice age, the Earth cycles in and out of glaciation, freezing for tens of thousands of years, thawing temporarily, and then freezing again. As the glaciers warm, water floods back across the

land, filling valleys and carving out new tracks in the landscape. Sea levels rise, and winds and currents shift. In fact, we are in the middle of an ice age right now – but we are in a temporary thaw that began around 11,000 years ago. These warm periods are known as 'interglacials' and we don't know exactly how long they last for. Ice sheets still cover Antarctica and Greenland, trapping 75 per cent of Earth's fresh water, and when these finally melt, it will mark the end of the current ice age. Until then, join us as we delve into the history of ice on Earth.

"Vast glaciers form at the poles, creeping towards the equator"

Trigger point

Earth's temperature depends on where it's at in its Milankovitch cycles

The Sun warms our planet, but the amount of heat we receive varies drastically over years, decades and millennia. This is because the Earth's orbit, tilt and axis angle fluctuate in three different patterns, collectively known as the Milankovitch cycles.

The first cycle is known as eccentricity. Earth moves around the Sun in an elliptical orbit, coming in close and then moving further away again. However, the shape of this orbit changes

over time, becoming more elongated (or 'eccentric') and rounder in a cycle that lasts 100,000 years.

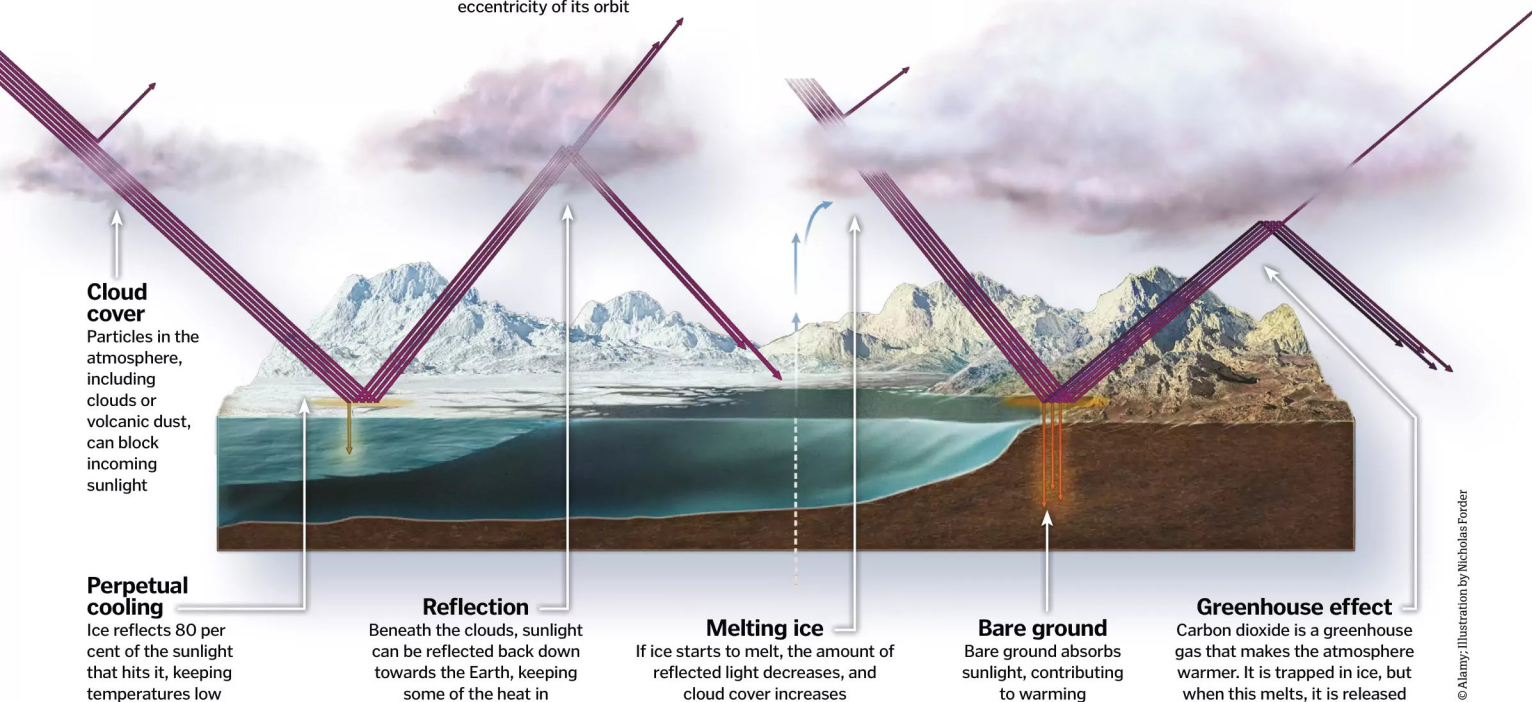
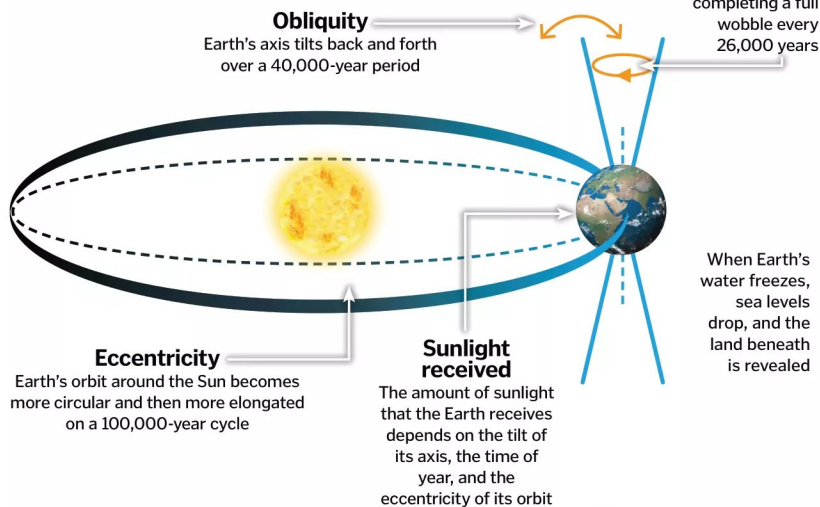
The second cycle, known as obliquity, refers to the tilt of Earth relative to the plane of its orbit, which varies from 22.1 to 24.5 degrees over a 40,000-year period. The bigger the angle of the tilt, the more extreme the seasons are on our planet. Finally, Earth also wobbles slightly as it spins, a little like a spinning top as it slows down.

This wobble is known as precession, and it takes 26,000-years to complete one cycle.

The amount of solar energy that reaches Earth depends on where it is in all three Milankovitch cycles. At times when the planet receives the least energy, summer temperatures are coldest, and an ice age may be triggered. But the planet's fate also depends on a number of other factors, including the position of continents, ocean circulation and composition of the atmosphere.

The making of an ice age

Several factors come together to tip the Earth into a big freeze





The last glacial period

What did the world look like at the height of the last ice age?

Cordilleran ice sheet

A second, smaller ice sheet periodically covered the northwest of North America

Laurentide ice sheet

This ice sheet started in Canada, and gradually crept over the northeastern United States

North America

Greenland ice sheet

Today, the Greenland ice sheet is the largest in the Northern Hemisphere, and contains eight per cent of Earth's fresh water

Pacific Ocean

South America

Atlantic Ocean

Patagonian ice sheet

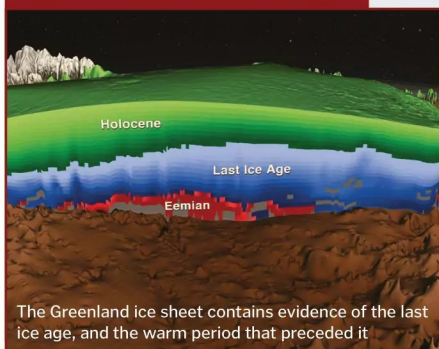
Most of the land in the Southern Hemisphere remained ice-free, but a sheet formed in South America

Antarctic ice sheet

Antarctic ice is relatively new, appearing during the last ice age. It's now the largest ice sheet on Earth

Geological evidence

Ice sheets are made from layers of ice and snow, laid down year after year. As more layers build up, the ones below become compacted. Drilling down into glaciers allows researchers to recover cylinders known as ice cores, which contain information about the age of the ice and the climate at the time it was laid, tracing back hundreds of thousands of years. For information further back in time, sediment cores can be taken from the oceans, providing data about the Earth millions of years ago. More recently, scientists have used ice-penetrating radar to detect layers under the surface of the Greenland ice sheet.



Earth's ice through the ages

Our landscape has changed dramatically over the last 2.4 billion years

3 BILLION
YRS AGO

2.4-2.1 BILLION YRS AGO

1 Snowball Earth
Our entire planet froze over during the first ever ice age, called the Huronian.

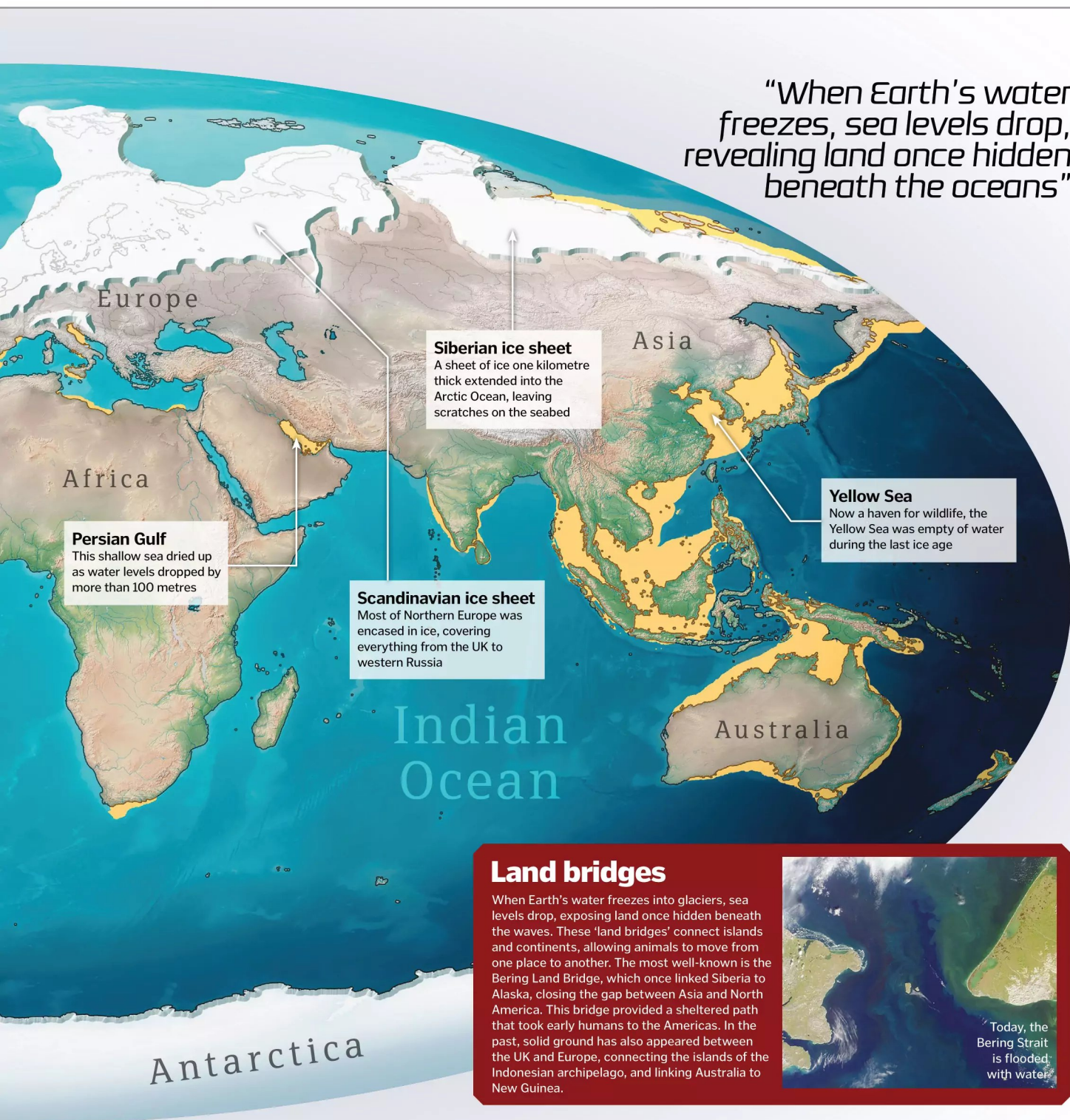
850-630 MILLION YRS AGO

2 Slushball Earth
During the Cryogenian ice age, a band of liquid ocean remained at the equator.

460-430 MILLION YRS AGO

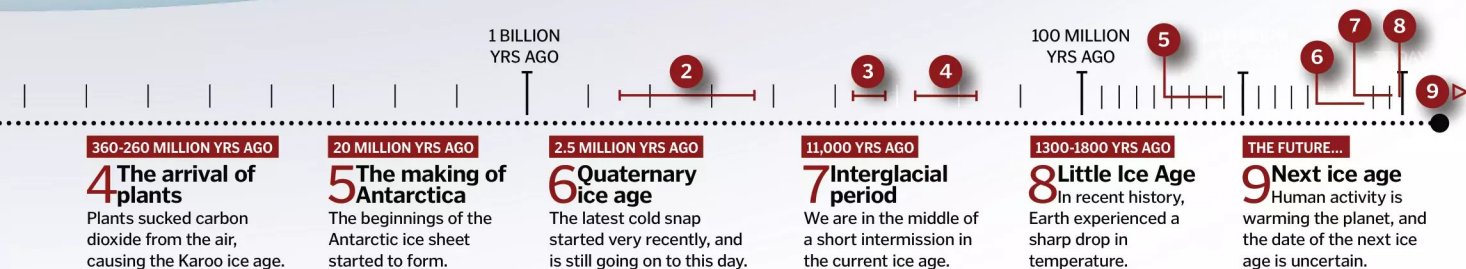
3 Mass extinction
The Andean-Saharan ice age accompanied the second largest mass extinction in history.

2 BILLION
YRS AGO



Land bridges

When Earth's water freezes into glaciers, sea levels drop, exposing land once hidden beneath the waves. These 'land bridges' connect islands and continents, allowing animals to move from one place to another. The most well-known is the Bering Land Bridge, which once linked Siberia to Alaska, closing the gap between Asia and North America. This bridge provided a sheltered path that took early humans to the Americas. In the past, solid ground has also appeared between the UK and Europe, connecting the islands of the Indonesian archipelago, and linking Australia to New Guinea.





The hardened survivors

Meet the giant beasts that conquered the frozen wilderness

Before the end of the last ice age, Earth was inhabited by weird and wonderful mammalian megafauna. Food was abundant, allowing animals to grow to enormous sizes, and the larger they got, the more protection they had from the cold. Not all of the animals that lived during the ice age inhabited the coldest parts of the planet; many, like ground sloths and sabre-toothed cats, preferred to live in warmer and more temperate regions further south.

There were also many true ice survivors, including fur-covered woolly mammoths, musk oxen, and giant dire wolves. Their stocky bodies helped to minimise heat loss through their skin, and layers of fat and hair provided thick insulation. However, when the temperatures started to rise, these animals began to struggle.

During interglacial periods, glaciers melt and sea levels rise; valleys flood and lakes appear in the landscape. Ocean currents change direction, and winds shift. And as if that weren't enough pressure, at the end of this particular ice age, humans were roaming the landscape with spears. Our ancestors competed with top predators, and hunted some of the largest animals. Mammoths and mastodons were 'keystone' species, so large and numerous that their activities carved out vital niches that other animals needed for survival. But around 50,000 years ago, the ice age megafauna started to die out, and by the time the glaciers had retreated, at least 177 large mammal species were extinct.



Sabre-toothed cats had 15cm canines

"At the end of the ice age, humans were roaming the landscape with spears"

Sabre-toothed cat

There were three species of sabre-toothed cat, all found in the Americas. They were similar in size to modern lions, but with shorter legs and significantly larger teeth. Their curved canines were over 15 centimetres long, and their mouths opened almost twice as wide as those of modern cats. Surprisingly, however, their bite force was nowhere near as powerful as a lion's. Although they are often called tigers, the colour and patterning of their fur is not known and they are not closely related to modern tigers.

Woolly mammoth

These iconic ice age animals were covered in thick hair and layers of insulating fat. Unlike modern elephants that have large ears to aid heat loss, mammoths had small ears to conserve heat, and even their blood was adapted to cold weather. Their haemoglobin – the molecule that transports oxygen in the blood – functioned over a much wider temperature range than that of modern elephants, allowing oxygen to reach their extremities even in the freezing cold.



Dire wolf

These prehistoric wolves were slightly larger than their modern counterparts, with short legs, broad heads, and smaller brains. While grey wolves use speed and teamwork to wear their prey down, these snow hunters are thought to have preferred ambush tactics. Grey wolves existed alongside these fearsome hunters but 10,000 years ago, dire wolves had disappeared, along with other ice age predators like sabre-toothed cats and American lions.



Other ice age critters

Giant beaver

These rodents were the size of bears, but their teeth were markedly different to those of modern beavers. There is no evidence that they built dams.

Ice age horse

Horses went extinct in the Americas 11,000 years ago, but they managed to survive in Eurasia and Africa. Modern horses in the Americas – as well as donkeys and asses – are the descendants of these survivors.

Musk ox

These heavy-set, woolly animals almost went extinct due to hunting during the last ice age, and the warming climate that followed. There are still some musk oxen in Canada today, but their numbers are vastly reduced.

American lion

Larger than modern lions, and with longer legs, these animals would have had to compete with sabre-toothed cats and short-faced bears for prey.

Mastodon

Relatives of mammoths, these elephant-like animals had long trunks and woolly hair. Some fossilised bones show evidence of tuberculosis, which could have been one of the factors leading to their extinction.

Stag-moose

With stilt-like legs, these animals were adapted to pick their way through damp marshland and boggy ground. They had large, complex antlers and faces similar to modern-day elk.

Ground sloths

Megatherium, or ground sloths, were the size of modern-day bison. They lived in the savannahs, forests and grasslands of North America, subsisting on a plant-based diet. They had long hair, huge jaws and powerful claws, which they used for digging and reaching up to tear leaves off branches.



Short-faced bear

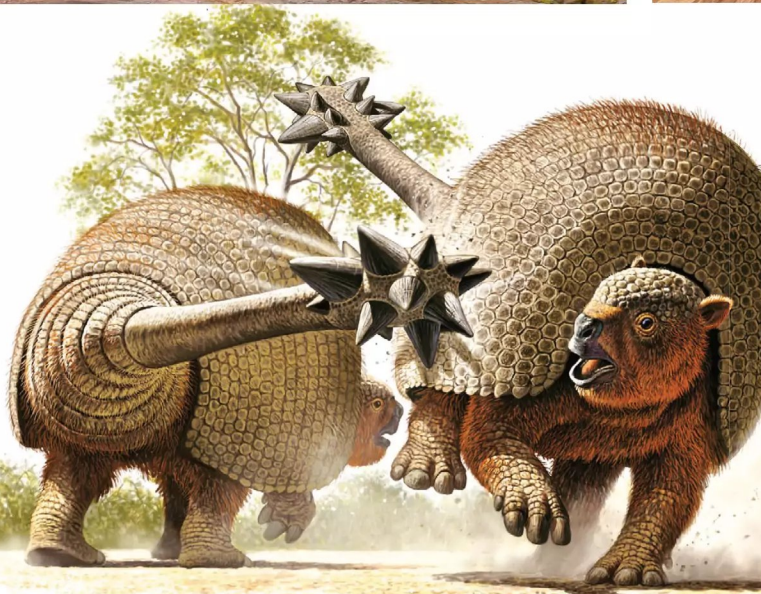
These ferocious bears are thought to have been the fastest of their kind, with front-facing feet that allowed them to reach speeds of more than 64 kilometres per hour. Their blunt snouts are thought to have helped them to get the maximum amount of air into their lungs while chasing their prey.



Glyptodonts

These bizarre-looking beasts were the size of a car, and the heaviest weighed more than a ton. Related to modern armadillos, they had a protective exoskeleton made from plates of bone

called osteoderms, and a fearsome-looking clubbed tail. While armadillos can flex their armour, glyptodonts had fused bones with rigid shells that turned them into walking tanks.





Living in a frozen world

How did early humans survive the ice age?

Early humans had begun to explore Europe, Asia and North America by the time the last glacial period set in around 110,000 years ago – this is what is often referred to as *the Ice Age*. Although many humans lived far enough to the south that they escaped the advancing ice, some had to brave fierce drops in temperature. They had three choices: migrate, adapt or die.

Humans weren't alone in their struggle. Another hominid species, Neanderthals, were also attempting to brave the cold. They were stockier than humans, with shorter forearms and shins, which would have helped to conserve body heat. Neanderthals built simple shelters, used animal skins for blankets, and kept themselves warm beside wood-fuelled fires. In mild conditions, they hunted red deer, and as it grew colder, they switched to reindeer. Eventually, when the landscape froze, they moved south in search of warmth.

However, humans had something that Neanderthals did not: advanced technology and sophisticated communication skills. They moved south to escape the worst of the cold, but some were still exposed to chilling temperatures and challenging environments. They learnt to burn bones when wood was scarce, built more complex shelters, and traded over great

distances, thereby making the most of their social networks.

Humans banded together and used sharp tools to hunt large animals like mammoths and mastodons, securing the biggest calorie payoff for their efforts. And when the meat had been consumed, they made needles and stitched the skins into well-fitting clothes. Neanderthals were extinct by the time of the glacial maximum, 20,000 years ago, but humans' intelligence and ingenuity helped them to cling on through the cold.

"Humans moved south to escape the worst of the cold"

Big game

Large animals like mammoths and mastodons provided huge numbers of calories to teams of hunters

Skins

Pelts were removed from hairy animals, and stitched into clothes using primitive needles

The secrets of survival

Clever thinking and advanced technology allowed humans to make it out alive



Hunter-gatherers

Ice age humans were hunter-gatherers, foraging for edible plants and killing animals for meat and skins

Stone Age tools

Flint could be chipped to produce a sharp point, allowing hunters to take on large, thick-skinned animals

The end of the ice age

What caused frozen Earth to thaw?



20,000 years ago

Towards the end of the last ice age, Earth tilted on its orbit, pointing the Northern Hemisphere towards the Sun. With more light and more heat striking the frozen surface, ice sheets in this area finally began to melt, and water flooded into the Atlantic Ocean.



19,000 years ago

The influx of cold water into the Atlantic disrupted the ocean currents, slowing the flow of warm water moving up from the south. With nowhere to go, these hot streams remained in the Southern Hemisphere, warming oceans and melting ice.



17,500 years ago

The flow of ocean currents affects the wind, and with the disruption in the north, winds pushed downwards. As the southern glaciers melted, more water was released into the oceans, and with it came carbon dioxide - a greenhouse gas that helps to trap heat.

Using the landscape

Sheltered areas in low-lying land would have provided some protection against the cold weather

Migration

Moving south, and sticking to sheltered, ice-free areas would have helped humans to survive the worst of the cold

Trade

Different groups traded across long distances, helping to maximise the use of different environments

Shelter

Some shelters were built with hearths inside to provide additional heat

Community

Symbols and communication allowed groups of people to work together to plan for the future

Fire

Wood was scarce in some places, so humans burnt bones as fuel

Is winter coming?

The impact of humans on Earth could affect the forecast

Technically, we are still in the middle of an ice age. The cold period that saw the rise and fall of woolly mammoths has not yet ended. We are in an interglacial period, and if history is anything to go by, these last for around 15,000 to 20,000 years.

11,000 years have already passed, but whether another cold snap is around the corner is a matter of debate. In the late 17th century, there was a Little Ice Age, during which time rivers froze and ice fields refused to melt during the summer. This is thought to have been caused by a period known as the Maunder Minimum.

The Sun's changing magnetic field produces sunspots, which normally increase and decrease in a pattern that repeats every 11 years, but during the Little Ice Age, this cycle all but stopped. For 70 years, there were only around 50 recorded spots, when normally there would have been closer to 50,000.

In 2008, sunspots disappeared again, and when they eventually returned in 2014, they were weaker than at any other time on record. However, since the 17th century, humans have been busy expanding and industrialising, and, at least in part thanks to us, global temperatures are rising. Whether this will have an effect on the ice age cycle remains to be seen.

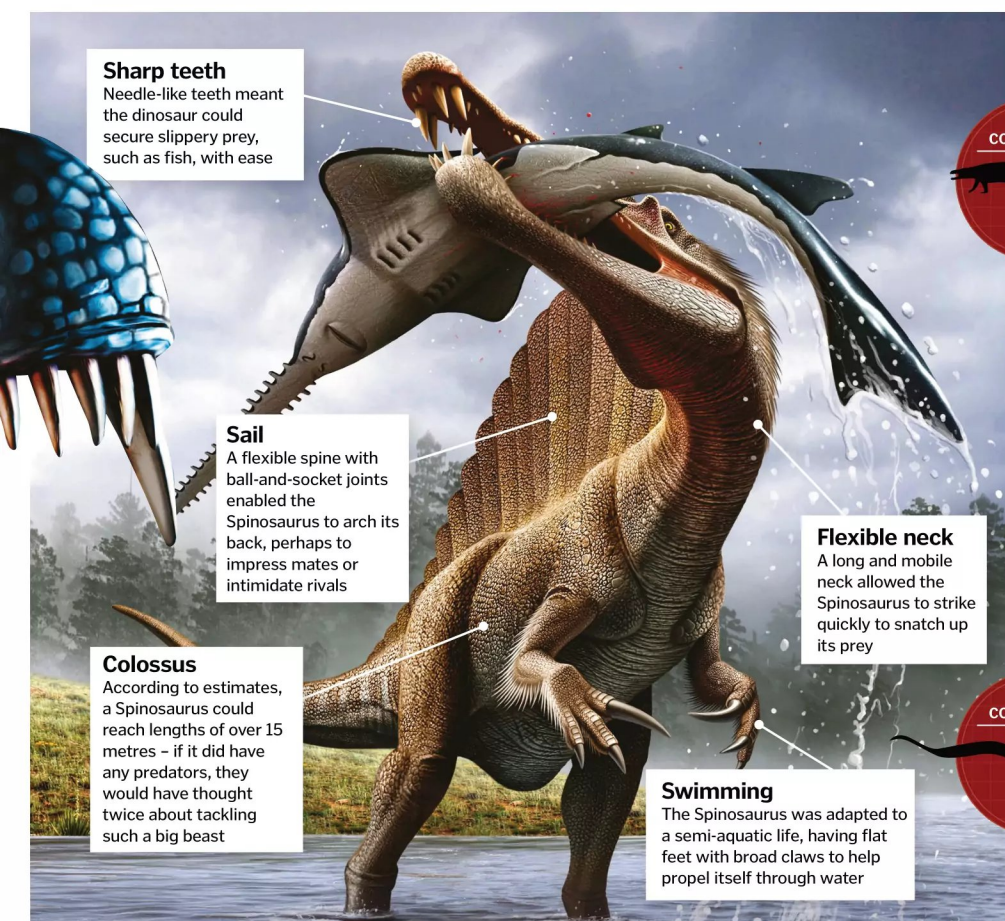
The Little Ice Age is thought to have inspired tales of white Christmases





Prehistoric monsters

Meet the enormous ancient predators that stalked the land, dominated the oceans and terrorised the skies



Colossal cretaceous carnivore

SPINOSAURUS ▶ 112-97 MYA

Move over T rex: the spine lizard was the true king

Nearly three storeys high and longer than a bus, the Spinosaurus was the largest carnivorous dinosaur to walk the Earth.

The 'spine lizard' roamed the coastal plains and swamps of North Africa in the mid-Cretaceous period. Unlike the Tyrannosaurus rex, Spinosaurus' teeth were not serrated, so they were not used for tearing through flesh; its conical teeth, powerful jaws and

long snout were better suited to snapping up large fish. It's thought that Spinosaurus was the first dinosaur to swim, and that it spent a lot of time in the water where it could snatch aquatic creatures with its razor-sharp claws. There is evidence to suggest Spinosaurus' snout openings and skull cavities were part of a pressure-detection system, so it could sense the movements of fish even in murky waters.

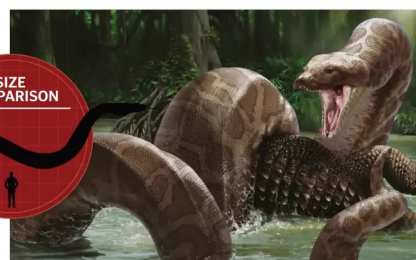
The giant carnivore's defining feature was the 1.5-metre-high 'sail' on its back, formed by tall vertebral spines. This may have been a display to attract mates or intimidate rivals, help regulate temperature, or possibly support a camel-like hump of stored fat that Spinosaurus could build up when food was plentiful.



Mega monitor lizard

VARANUS PRISCUS ▶ 1.8 MYA-40,000 YA

Also known as Megalania, these giant goannas of eastern Australia were the largest land lizards of all time. They could grow to lengths of over five metres and weigh as much as 600 kilograms. Megalania had razor-sharp teeth and claws, perfect for tearing into its prey. These large lizards compensated for their lack of speed by lying in wait to ambush victims, and sought out carrion using their excellent sense of smell.



Super-sized serpent

TITANOBOA ▶ 60-58 MYA

Reaching lengths of up to 15 metres, Titanoboa was one of the largest land animals on Earth following the extinction of the dinosaurs. These colossal serpents lived in the jungles of South America, devouring turtles and crocodiles in single mouthfuls. Titanoboa could hunt on land and in water, slithering or swimming up to its prey undetected, then suddenly leaping up to clamp its powerful jaws over the victim's windpipe.



Terror birds

PHORUSRHACIDAE ▶ 62-2 MYA

These terrifying predators of prehistoric South America were members of the Phorusrhacidae family, known as 'terror birds', and some could reach heights of three metres. Their main weapon was a sharp, hooked beak that could strike victims from above like a pickaxe. The birds' legs were also incredibly strong, and they may have used their feet to kill by repeatedly kicking, or thrown their prey violently to tenderise the meat.



Marine monsters

Lurking in the depths of prehistoric seas were a whole host of deadly aquatic giants

Sense of smell

Water was funnelled through the reptile's nostrils so it could smell its prey even in dark or murky water

Vice-like bite

Liopleurodon's large, powerful jaw muscles helped it keep hold of prey that tried to struggle free

Terrifying teeth

Liopleurodon's needle-like teeth were each about ten centimetres long, ideal for piercing the flesh of prey

A powerful pliosaur

What made Liopleurodon such a formidable Jurassic carnivore?

Strong swimmer

Long, paddle-like flippers helped the pliosaur push itself through the water and accelerate in short bursts to ambush prey

Intimidating size

Liopleurodon's length is hard to estimate accurately due to incomplete fossil records, but some pliosaurus may have reached 15 to 18 metres in size

Mighty ocean predator

LIOPLEURODON ► 160-155 MYA

A fierce killer with a bone-crunching bite

Liopleurodon was among the most powerful predators ever known on Earth, with a bite possibly even stronger than that of the mighty T rex. It belonged to a group of marine reptiles called pliosaurus, which were large with short necks. Liopleurodon's diet primarily consisted

of fish and squid, but it would occasionally seek out much larger prey. Huge bite marks that were found in plesiosaur fossils suggest that they were victims of the Liopleurodon's massive jaws, which were packed with sharp teeth. Scientists even estimate that these colossal carnivores

would have been strong enough to bite a car in half, if they had existed at the same time!

Liopleurodon may have also had a pale underside to help keep it camouflaged from prey below, allowing it to make ambush attacks despite its enormous size.

SIZE COMPARISON

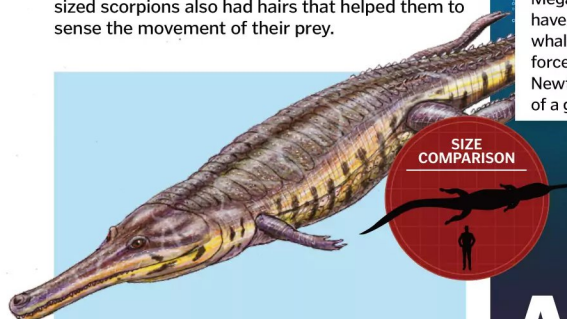




Giant sea scorpion

PENTECOPTERUS ► 467 MYA

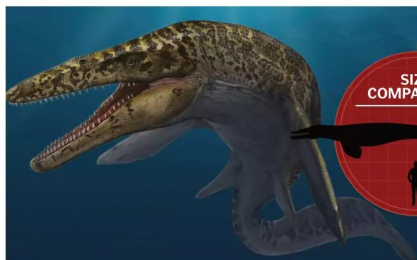
Over 200 million years before the first dinosaurs emerged, this nightmarish Pentecopterus was an important Palaeozoic predator. These arthropods grew to lengths of around 1.8 metres, and used their large limbs to grab prey. Young lived on the seabed while adults mainly resided in shallow waters to avoid larger predators. These super-sized scorpions also had hairs that helped them to sense the movement of their prey.



King-sized croc

MACHIMOSAURUS ► 130 MYA

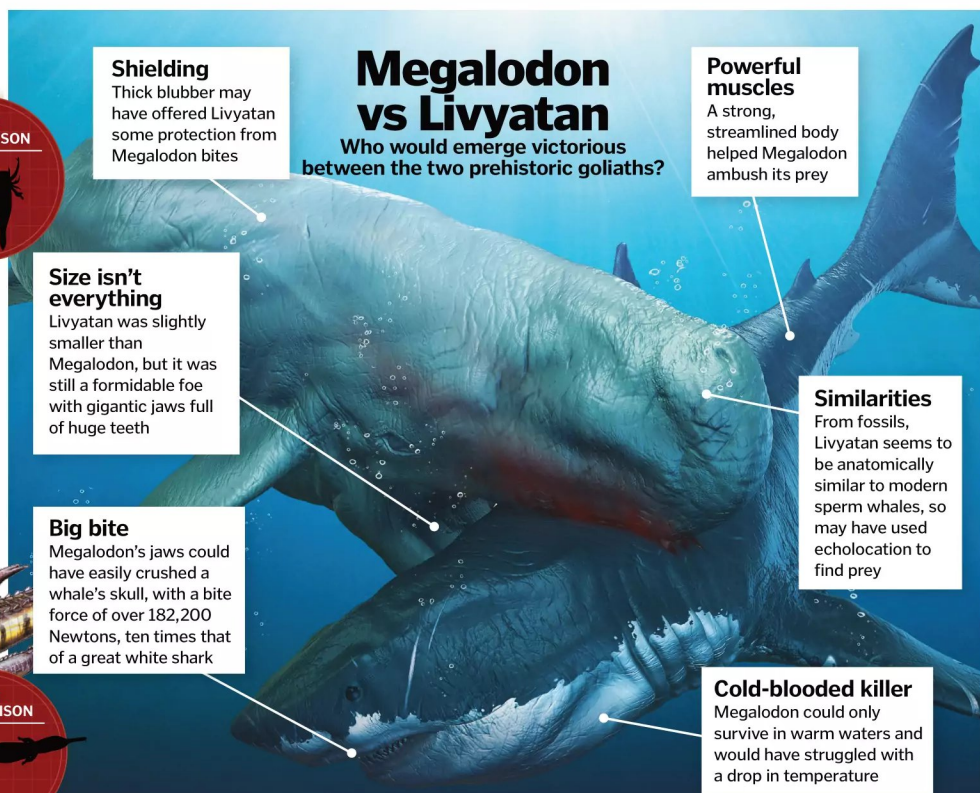
Lurking in Cretaceous seas, Machimosaurus was a colossal crocodile at nearly ten metres long, almost twice the size of its biggest modern relatives. Its teeth were best suited for crushing shells and crunching bones rather than slicing through flesh. Machimosaurus' main tactic was to hide in shallow water and, without warning, clamp its mouth shut on a turtle or fish. Once its prey was caught in the jaws, there would be no escape.



Apex ocean reptile

MOSAOSAURUS ► 80-66 MYA

The massive Mosasaurus was a giant aquatic lizard and dominant predator in Cretaceous-era oceans. Some grew to 15 metres or more, and had long, powerful tails to propel themselves through water. They preyed on reptiles, fish, sharks and shellfish, snapping their tough shells with powerful jaws. As an air-breather, Mosasaurus was unable to dive for prolonged periods, so it was limited to hunting near the ocean surface.



Megalodon vs Livyatan

Who would emerge victorious between the two prehistoric goliaths?

Shielding

Thick blubber may have offered Livyatan some protection from Megalodon bites

Size isn't everything

Livyatan was slightly smaller than Megalodon, but it was still a formidable foe with gigantic jaws full of huge teeth

Big bite

Megalodon's jaws could have easily crushed a whale's skull, with a bite force of over 182,200 Newtons, ten times that of a great white shark

Powerful muscles

A strong, streamlined body helped Megalodon ambush its prey

Similarities

From fossils, Livyatan seems to be anatomically similar to modern sperm whales, so may have used echolocation to find prey

Cold-blooded killer

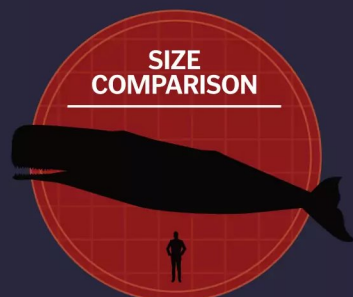
Megalodon could only survive in warm waters and would have struggled with a drop in temperature

A real-life leviathan

LIVYATAN ► 13-12 MYA

A killer sperm whale with one of history's biggest bites

Hebrew for 'leviathan', Livyatan was roughly the same size as a modern sperm whale, but it was a much more formidable hunter. The 50-ton beasts probably competed with Megalodon for food, preying on smaller whales, cetaceans like dolphins, and large fish. Livyatan teeth are possibly the largest of any animal at over 30 centimetres long, and its bite force could rival that of the Megalodon.

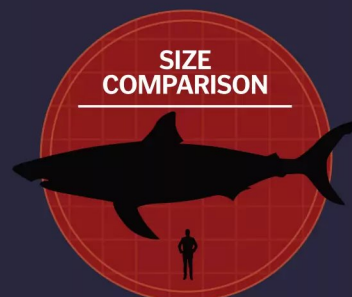


Super-sized shark

MEGALODON ► 28-1.6 MYA

Meet the colossal sharks that dwarfed great whites

These gigantic 75-ton sharks were so big that they could hunt whales with ease. Up to 20 metres long and equipped with a mouth full of teeth as large as a human hand, these mega-sharks made short work of dolphins, whales, seals, squid and other sharks. When faced with a turtle shell, they snapped it in two. It is estimated that Megalodon had one of the strongest bite forces of any animal that's ever lived, capable of crushing a small car.





Sky giants

The huge aerial predators that brought death from above

Deadly impact

Gathering momentum on a swoop, a 13-kilogram eagle could take down prey even bigger than itself, such as a moa

Dive bomb

Haast's eagles could strike from above at an estimated speed of 80 kilometres per hour

Talons

These eagles would use one foot to secure prey while the other crushed the neck or head

Haast's eagles were eventually driven to extinction as they competed with humans for moas, their preferred prey

Jumbo raptor

HAAST'S EAGLE ► 1.8 MYA-1400 CE

With talons the size of tigers' claws, these monstrous eagles preyed on the helpless herbivores of New Zealand's South Island. Swooping at speeds of up to 80 kilometres per hour, they could knock victims off their feet with the sheer force of impact. Their favourite prey were giant flightless birds called moas, which could weigh up to 250 kilograms. Compared to the size of its body, Haast's eagles' three-metre wingspan was relatively short. This meant that they would have killed moas on the ground rather than carry them away. Their terrifying, razor-sharp talons could quickly incapacitate victims by delivering crushing blows to their head or neck.

Plane-sized pterosaur

QUETZALCOATLUS NORTHROPI ► 70-65 MYA

Quetzalcoatlus was the largest-known species of pterosaur, the group of flying reptiles that lived alongside dinosaurs. With a wingspan of ten metres or more, it was roughly the size of a small jet plane. Its toothless beak suggests that it hunted small prey that didn't require chewing, such as baby dinosaurs, and possibly also scavenged for carrion. Quetzalcoatlus is also thought to have roamed on land, because it had small, cushioned feet that were suited to moving over firm terrain. If this is true, it may have hunted like a modern-day stork, snatching small prey up in its beak.

Land and air

Quetzalcoatlus' wide wings helped it to soar, while its compact feet helped it move quickly across the ground

Sharp beak

Using its pointed beak, Quetzalcoatlus could snap up small dinosaurs

Wing tips

Quetzalcoatlus' wings stretched from its elongated fourth fingers to the top of its legs

Quetzalcoatlus had a crest on top of its head, possibly brightly coloured to attract mates



Biggest bird

ARGENTAVIS ► 6 MYA

Dwarfing even the Haast's eagle, Argentavis is one of the largest birds to have ever lived. Its seven-metre wingspan meant it was suited to gliding rather than flapping, and it used air currents to stay aloft. Argentavis' massive size made it impossible to perform a running take-off, so it relied on height to get airborne, taking advantage of slopes and headwinds like a hang-glider pilot. The so-called 'monster bird' could use its sharp talons and hooked beak to attack its prey, soaring over vast areas of land in search of victims. Argentavis may have also scavenged, its intimidating size driving other hunters away from a kill, in order to help itself to the carcass.

Gliding bird

Argentavis' long wings enabled it to glide on wind currents and updrafts

Achieving flight

To get airborne the bird would run down slopes and leap into the air

Scavenger

Argentavis' imposing size meant it could scare away other predators from their own kills



Gigantic fly

MEGANEURA ► 300 MYA

One of the biggest insects to ever exist, the Meganeura was a member of the griffinflies, which are closely related to dragonflies. This prehistoric insect benefited from a higher percentage of oxygen in the atmosphere in the period in which it lived. This allowed it to grow to and maintain its huge size. It used its large eyes to spot prey such as small amphibians and other insects, which it grabbed with its legs while in midair.

The Meganeura's 75-centimetre wingspan was larger than that of a magpie



Why were prehistoric animals so big?

It had previously been accepted that prehistoric animal size was a result of Cope's Rule. Named after American palaeontologist Edward Drinker Cope, the theory suggested that dinosaur gigantism was down to the notion that animals naturally evolve to be bigger. When mass extinctions occur, new smaller animals replace the larger extinct ones, and the process begins anew. As it has 'only' been 66 million years since the Cretaceous mass extinction, and 12,000 years since the last ice age, animals on Earth are now smaller because they haven't yet had enough time to evolve to reach such large sizes once again.

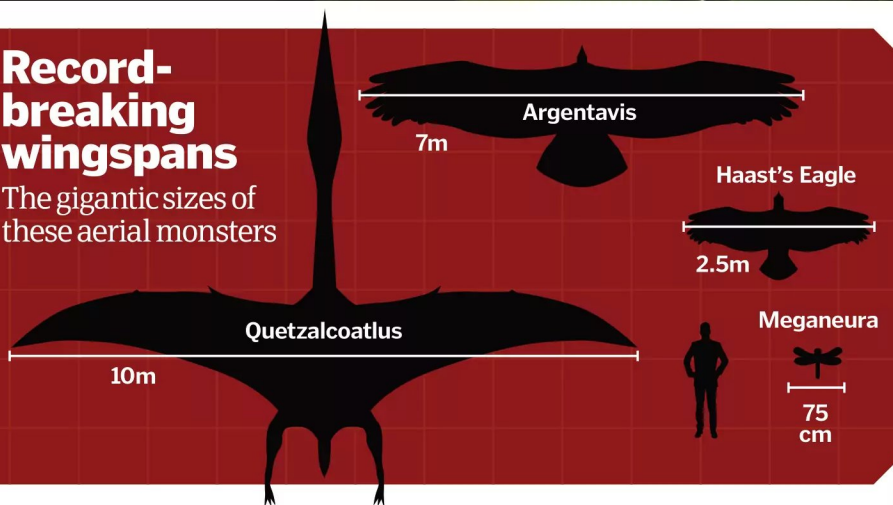
Another theory suggested that environmental factors, such as higher oxygen levels and warmer temperatures, could have played a significant role in gigantism. Cold-blooded reptiles benefited from the toasty climate as it allowed for efficient digestion, circulation and respiration, as well as an abundance of vegetation to consume.

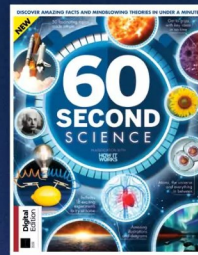
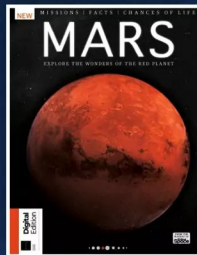
More recent research and fossil discoveries have cast doubt on both these theories, though. Some creatures seemed to evolve to be smaller rather than larger over time, and many different-sized animals existed at the time. One explanation for why dinosaurs in particular were typically large is because they were physiologically similar to birds. Their bones had air pockets in them, making even large species relatively light, so they wouldn't collapse under the weight of their own bodies.

Not all of the biggest beasts were prehistoric, though. In fact, the heaviest animal ever to exist on planet Earth is still alive today: the blue whale. Marine animals can grow to epic proportions because the buoyancy from water helps to balance the force due to gravity. This supports their considerable masses, and allows for far larger body sizes than on land.

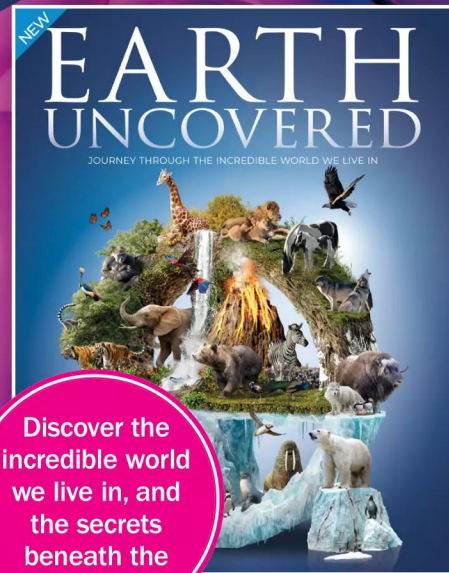
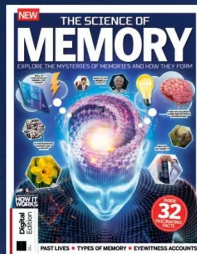
Record-breaking wingspans

The gigantic sizes of these aerial monsters

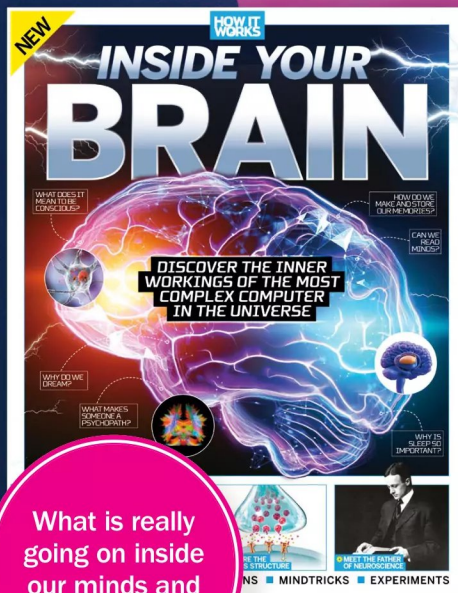
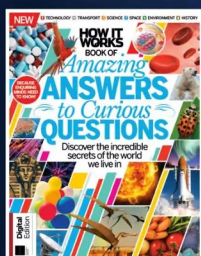
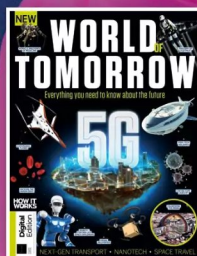
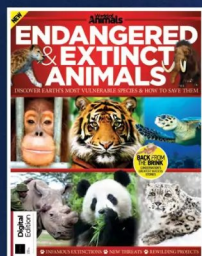




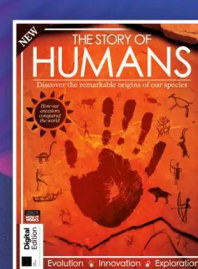
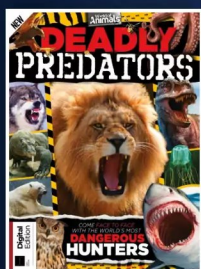
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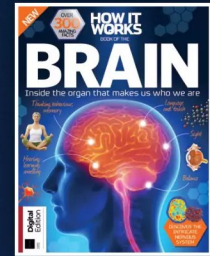
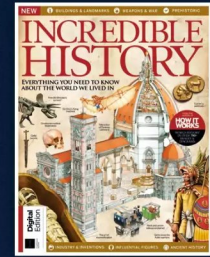
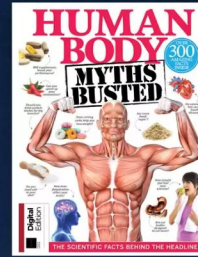
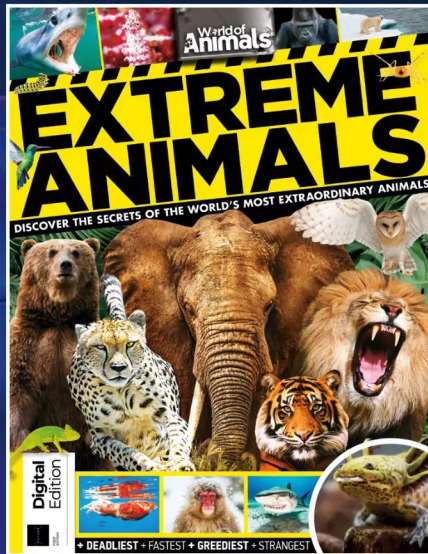
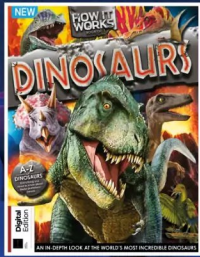
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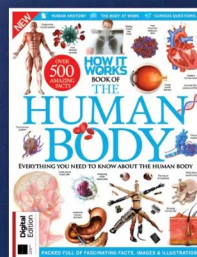


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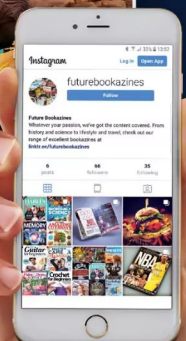
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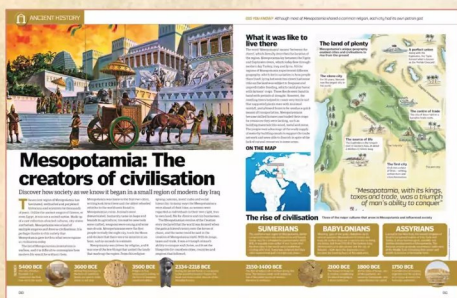
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